

Functionality and design in a portable PC cooling device (PCD)

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Introduction

Computer processing units produce significant heat as a byproduct of intense processing. While the central processing unit (CPU) of a personal computer (PC) is usually attached to a heat sink and fan, factors such as case temperature, case airflow, environmental temperature and especially air intake temperature affect the cooling capability of a PC [1]. Regarding a laptop specifically, the compact nature of the build prevents efficient airflow and heat dissipation from the CPU, leading to higher core temperatures. In turn, this leads to increased outer casing and component temperature, which is not only unpleasant for the operator, but also unhealthy for the PC as higher temperature casing creates an insulating effect and promotes higher air temperature inside the case. Modern CPUs have performance throttling features built in based on core temperature in an attempt to curb thermal damage, but this feature does negatively affect user experience.

To reduce the temperature of the outer casing and create a more effective low temperature airflow, laptop PC operators can obtain cooling pads which provide a fan cooled platform for laptops to sit on. The example such a pad used in this report contains 3 centrally placed fans in a triangular arrangement, which blow upwards towards the bottom of the laptop. While this does help to reduce the surrounding air temperature, the laptop PC this report is designing for has outflow vent facing outwards from the base of its case, so an upwards air current may actually hinder efficient air flow. Additionally, the air intake may not necessarily be receiving a low temperature airflow depending on placement. Furthermore, the current heating pad examined here does not travel well, as it has many loose parts is too wide for the profile of the laptop, meaning it also takes up more space than necessary in both packing and operation. The fan speed of this cooling pad is also non-variable and while it is quiet, it does not provide adequate cooling when the laptop is in high performance mode.

This begins to inform what some of the key customer requirements might be.

Key customer requirements

The following customer requirements were identified in the first stage of the design process:

1. The operator requires that the device draw heat away from the PC
2. The operator requires that the device expel drawn heat from itself

3. The operator does not want to be disturbed by excess noise or vibration
4. The operator requires cooling power to be adjustable
5. The operator does not want the normal physical operating procedures of the PC to be significantly altered by the device.
6. The operator requires the device to be safe to use for any user
7. The operator requires the device to be easily transportable for a pedestrian.

Requirements 1 and 2 were trivially devised as natural features of any cooling device. The first being necessary for the actual cooling of the device, and second being required for continual operation over time. As an additional core performance related requirement, number 4 was identified as a wanted feature during criticism of the current design.

Requirements 3, 5, 6 and 7 were introduced as user experience/safety driven requirements. While the PC operator is likely to wear mild hearing protection in the form of noise cancelling headphones, significant enough volume and vibration would be likely to cause disruptive or even harmful effects on the operator, hence requirement 3. Requirements 5 and 6 touch on a similar vein of user safety, with the former mostly considering operator posture and the latter being a catch-all for any other operator injury risks, i.e. electric shock, blunt or sharp injuries. Requirement 5 also ties in with requirement 7, which both attempt to improve the operator's user experience through comfortable posture and convenient portability.

Initial subjective evaluation placed requirements 1, 2 and 6 as extremely important with the remaining requirements as somewhat secondary in importance, however after performing a pair-wise comparison via a comparison matrix, requirement 5 was also identified as being important, more so than 1 or 2 in fact (fig. 1). While this initially seemed counterintuitive, this led to a deeper consideration of the notion that it doesn't matter how well a device cools if it's unusable for the operator.

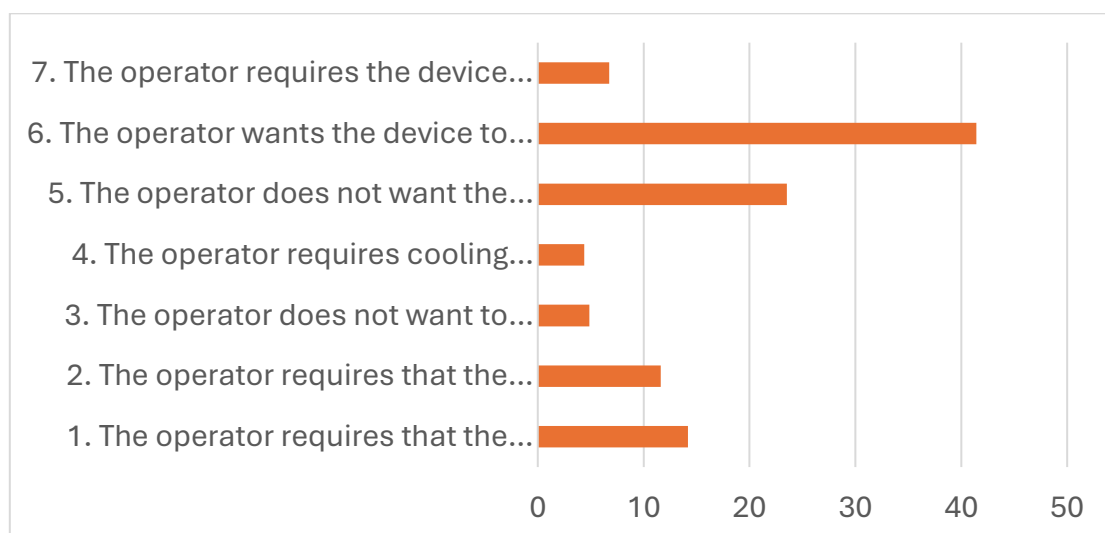


Fig. 1: A chart showing relative importance of customer requirements

As such, the relative importance of each requirement, as derived from the pair-wise comparison, was represented by a numerical weighting as seen in Table I, with 1, 2, 5, and 6 being the only double-digit requirement weightings.

TABLE I
RATIONALISED REQUIREMENTS

	1	2	3	4	5	6	7	Total Normalised
1. The operator requires that the device draw heat away from the PC	1	2	5	9	0.2	0.11	5	14
2. The operator requires that the device expel drawn heat from itself	0.5	1	5	9	0.2	00.11	5	12
3. The operator does not want to be disturbed by excess noise or vibration	0.5	0.2	1	0.5	0.2	0.11	1	4.9
4. The operator requires cooling power to be adjustable	0.11	0.11	2	1	0.2	0.11	0.2	4.4
5. The operator does not want the normal physical operating procedures of the PC to be significantly altered by the device.	5	5	5	5	1	0.2	2	24
6. The operator wants the device to be safe to use for any user	9	9	9	9	5	1	9	41
7. The operator requires the device to be easily transportable for a pedestrian.	0.2	0.2	1	5	0.5	0.11	1	6.8

Critical system functionality

From this point, a use case was developed (see Appendix A) which outlined the pre- and post-conditions as well as the basic, alternative and exception flows expected from the new design.

Pre- and post-conditions

The pre- and post-conditions were relatively rudimentary. The pre-conditions were essentially that the PC is on, the PC is hot, and there is an available power supply route.

The post-conditions were that the PC is running at a lower temperature, the user experience is not significantly affected, and that the PC is still functional.

Basic flow

The basic flow, in other words the expected sequence of events for device function, was outlined as such:

1. The user interfaces the PCD with the PC, both physically and electronically.
 - a. The PCD should physically integrate with the PC such that it does not significantly affect usage.
 - b. PCD should connect electronically with the PC in any way appropriate for data or power transmission that might be needed.
2. The user turns the PCD on.
 - a. The PCD should remain inactive until user direction is given via off/on switch.
3. The user operates PC as normal.
 - a. The PCD should transfer heat away from the PC system at a rate faster than the heat accumulates.
4. The user may be able to adjust cooling power manually or automatically using software/hardware integration.
 - a. The PCD must respond to software commands with changes in cooling power.

In retrospect, this basic flow did not include the process for ceasing device function, this was captured later in the functional analysis process.

Alternative flow:

The alternative flow demonstrates what happens when the user interacts with the system outside of the normal expected flow:

1. The user does not interface the PCD with the PC.
 - a. The PCD will not cool the PC, but may function regardless, if powered on.
2. The user does not turn on the PCD.
 - a. The PCD will not function.
3. The user operates the PC beyond the bounds of normal use.
 - a. While the PCD will cool, it may not be sufficiently powerful to dissipate the heat produced, resulting in possible PC or PCD damage.
4. The user gives inappropriate software commands to the PCD.
 - a. The PCD's software parameters should be bounded, such that any inappropriate commands return to a default parameter.

During later stages of the design process, namely Design Failure Mode and Effects Analysis (DFMEA), additional alternative flows were identified, but this was an effective jumping-off point to begin to design features in such a way that alternative flows could be dealt with effectively.

Exception flow

The exception flow lays a foundation for future failure mode analysis by identifying the more apparent routes for device failure:

1. The software or software/hardware integration fails to give appropriate commands.
 - a. If the software fails, the PC, PCD or user of both may be damaged due to heat or mechanical effects.
2. Power supply interference
 - a. The PCD may not function if power is required but not supplied.
3. Mechanical interference
 - a. If the PCD has mechanical operating principles, it may fail to cool sufficiently or at all, if mechanical issues such as wear and tear occur.
4. Environmental temperature interference
 - a. The PCD may fail to cool sufficiently or at all if the environmental temperature beyond a certain point, depending on the operating principles.

Derived functions:

From this use case an operational requirement statement was obtained:

“To draw heat away from a processing unit housed inside a personal computer at a variable rate without exposing the operator or operating environment to unnecessary disruption or risk, then disassemble into a portable form.”

Using this, overarching functions were derived and subsequently 14 generic functions were obtained:

Prepare device:

1. Interface hardware
2. Interface supply
3. Interface physically

Cool PC

4. Draw heat
5. Expel heat
6. Vary rate

Become portable

7. Disconnect hardware
8. Disconnect supply
9. Separate physically
10. Pack up

Mitigate effects

11. Manage volume
12. Manage vibration
13. Prevent electric shock
14. Ergonomic design

At this stage, the importance of each function was evaluated by assigning it an impact factor (1 – Mild impact, 3 – Moderate impact, 9 – Significant impact) against each of the operational requirements. By factoring in the initial weighting of the requirements, a relative importance between all functions could be established, as seen in fig. 2.

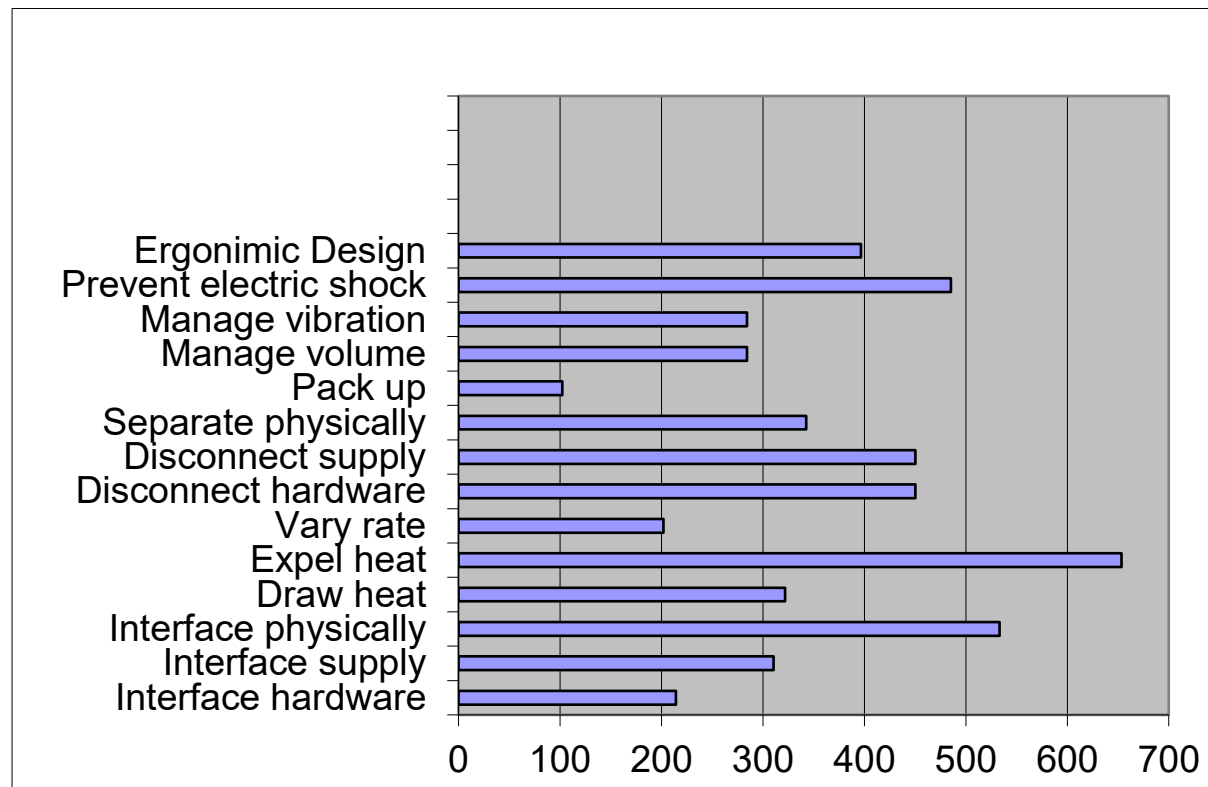


Fig. 2: A chart comparing the importances of each function

These new weightings for each function were then used to inform which design concepts were most effective at reaching the original operation requirements.

Concept derivation and design choices

Functional means analysis was used to assess the suitability of various suggested means against the function set. Means were assessed via a simple traffic light system, and compromises were made on the lowest scoring function of packing up (i.e. portability). Once suitable means were identified they were grouped into two concept designs, simply named V1 and V2, shown in Table II.

TABLE II
DESIGN CONCEPT FEATURES FOR CURRENT, V1 AND V2 IMPLEMENTATIONS

	Current	V1	V2
Interface hardware	Power only	Dual data and power cable	Data cable
Interface supply	Power cable	Dual data and power cable	13A mains cable

Interface physically	Raised steel platform with friction pads	Raised adjustable aluminium platform with friction pads	Raised adjustable copper platform with friction pads.
Draw heat	3 centred fans facing up	Downward fans for output, upwards for intake	Evaporator coil and upwards fan at intake, coil-connected heat sink and downward fan at output.
Expel heat	Air dispersion via fans	Downward fans at outtake	Condenser/compressor and fans with extractor tubing.
Vary rate	None	Adjustable fan speed through data cable	Adjustable fan speed and compressor settings with manual override
Disconnect hardware	Off switch and unplug cable	Off switch and unplug cable	Off switch and unplug cable
Disconnect supply	Off switch and unplug cable	Off switch and unplug cable	Off switch and unplug cable
Separate physically	Lift from platform	Lift from platform	Lift from platform
Pack up	Flat platform and loose cables	Flat platform, slim profile bag or loose packing	Thicker, heavier platform and cables require separate bag
Manage volume	Bearings on fans	Fans (bearings) are rate limited and adjustable	Adjustable fan (with bearings) speed and compressor settings.
Manage vibration	Bearings on fans	Fans are placed on bearings and platform legs are padded.	Fans are placed on bearings and platform legs are padded.
Prevent electric shock	IET compliance and earthing through PC while plugged in. Low voltage system.	IET compliance and earthing through PC while plugged in. Low voltage system.	IET compliance and earthing while plugged in. Mains voltage.
Ergonomic design	Elevation of PC is mild and adjustable.	Elevation of PC is mild and adjustable.	Elevation of PC is adjustable but significant.

In design V1, almost all of the initial criticisms of the current design are solved for. Fans face in the correct directions relative to the air input or output vents they are placed neat resulting in a complete airflow cycle of cool air in, hot air out and away.

Additionally, the USB port that's already in use in the current design was leveraged to also supply data connection, allowing integration with preexisting system software to manually or automatically change fan RPM. The steel platform of the older design was replaced with an aluminium alternative which not only reduces the mass of the PCD but

also increases the thermal conductivity of the platform surface, allowing for surface cooling of the PC casing; this solves two problems with one design choice. The design features around safety and ergonomics were mostly adequate/standard in the current model and did not need to be improved, at risk of overengineering introducing a new failure mode. A separate bag for the PC cooler was a significant wanted feature in the initial criticism of the current design and while one is incorporated in the V1 concept, it should be noted that the portability related function was significantly devalued during evaluation.

The V2 design was a more high-tech approach to cooling and heat expulsion, with the main concept being that the air intake stream would be cooled via a refrigeration system's evaporation coil, which would also be connected to a heat sync that cooled output air from the PC's output vent. Due to the internal energy taken up by phase transition, refrigeration cooling is far superior to air cooling [2]. The connected condenser/compressor unit would then release this heat as hot air into a separate vent which could be connected to a flexible air duct for complete expulsion of hot air. One drawback of this system is that it requires an extra 13A cable for mains power which reduces packing efficiency and affects the safety considerations for the device. Other features were essentially similar to the V1, but the refrigeration system and choice of a copper grid (for better thermal conductivity [3]) significantly reduced the ergonomics and packing efficiency.

These 3 total designs (including the current) were compared against the initial customer requirements in a system Pugh matrix (Table III). Each design was subjectively evaluated against each customer requirement and given a score from -2 to 2. Cost was additionally considered with a weighting of 10.

As may be expected, the current design scored moderately poorly in every requirement except safety (req. 6) and the additional cost requirement. V1 scored highly against noise and fan adjustment requirements (req. 3, 4) as well as safety and portability (req. 6,7). Modest scores were also obtained in the two cooling requirements (req. 1,2) but due to their simple fan set ups, they did not achieve a maximum score. V1 scored similarly to the current design on cost, as fans are inexpensive. V2 achieved significantly higher scores in requirements 1 and 2 due to the superior refrigeration system, but fell behind V1 in requirements 3, 5, 6 and 7, almost entirely due to the bulky and inherently less safe refrigeration system. It is noteworthy that even the current design outperformed in requirements 5,6 and 7. Cost was a -2 score due to the expensive material and technological cost.

As such, design V1 was chosen for its final weighted score of 154, as compared to scores of 103 and 87 for the current and V2 designs respectively.

TABLE III
PUGH MATRIX COMPARISON OF ALL DESIGN CONCEPTS AGAINST RATIONALISED REQUIREMENTS

Requirements		EW	RW	C	V1	V2
The operator requires that the device draw heat away from the PC		5	14.17	0	1	2
The operator requires that the device expel drawn heat from itself		5	11.63	0	1	2
The operator does not want to be disturbed by excess noise or vibration		5	4.858	0	2	1
The operator requires cooling power to be adjustable		5	4.38	0	2	2
The operator does not want the normal physical operating procedures of the PC to be significantly altered by the device.		5	23.53	1	1	0
The operator requires the device to be safe to use for any user		5	41.43	2	2	1
The operator requires the device to be easily transportable for a pedestrian.		5	6.75	1	2	0
Cost		5	10	-1	-1	-2
Ranking even weighting				15	50	30
Ranking with requirement weighting				103	154	87

Features were also evaluated for their ability to fulfil their functions, resulting in a feature importance chart as seen in figure 3.

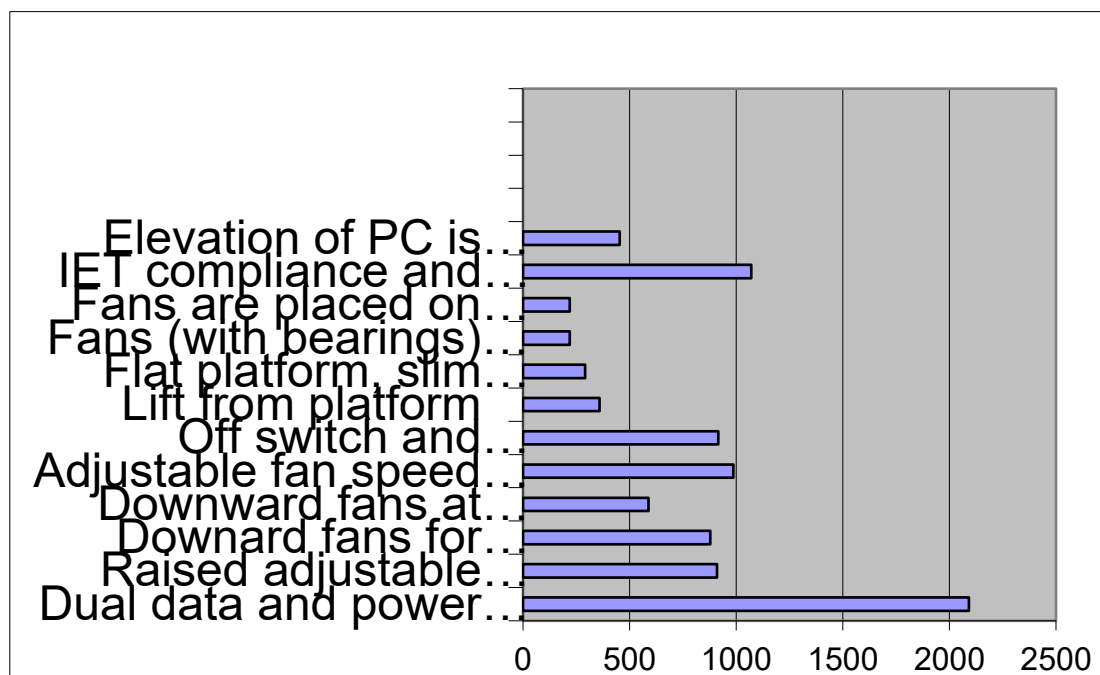


Fig. 3: A chart comparing the importances of each design means/feature

Potential failure modes

With design concept V1 chosen, design failure mode and effects analysis was performed (Appendix B), with the most significant failure mode for each function selected for analysis. Overall, similar themes were identified through each function, with almost every failure mode having a mechanical or electrical failure as the root cause. The most frequently identified detection mode was operator sensory detection, such as auditory detection of fan faults or touch detection of high temperatures. This presents an issue with the initial design concept because it relies too much on subject human sensory capabilities which are known to fail or be inconsistent. As such, numerous suggested interventions featured more robust, objective detection mechanisms such as temperature or sound detectors, and even more featured engineering interventions such as physical covers.

Each failure mode was scored on a scale of 1-10 for severity, occurrence and detectability, with a final rating being the product of all 3 (see fig. 4).

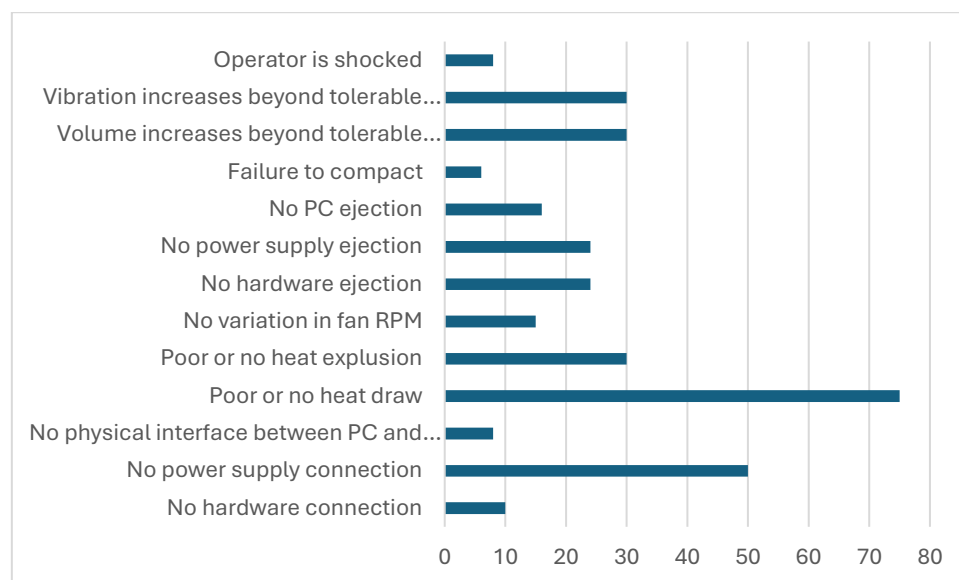


Fig. 4: A chart comparing the rating of each failure mode

For brevity, the highest and lowest rated failure modes will be discussed in detail below.

Prevent electric shock

Preventing electric shock's failure mode was stated as "Operator is shocked". This is considered a severity of 4 indicating failure of system and minor injury. While an electric shock is typically considered a significant injury, the low voltage system of a laptop is unlikely to be a particularly severe shock. Since the design concept for V1 featured IET compliant wiring and earthing, a shock is highly unlikely, resulting in an occurrence of 2. Furthermore, modern electrical installations come with many in-built safety features such as residual leakage current detectors (RCDs), miniature circuit overcurrent breakers (MCBs) and surge protection devices (SPDs). This would make a fault easily

detectable before the operator is exposed to it and would trigger a partial or full shutdown of the power supply. As such, the total rating of this failure mode was considered 8, with interventions being complete overhauls of the system to operate as a Safety Extra Low Voltage (SELV) system or a type two double insulated device.

Draw heat

The failure mode for drawing heat titled “Poor or no heat draw” was the highest rated failure mode. It was determined to likely be caused by myriad factors including electrical faults, mechanical faults, wear and tear, air pressure, air temperature and physical airway obstruction. Since the entire device is intended to be a cooling system, a failure to draw heat was considered a capability loss with no injuries, hence a severity rating of 5. The occurrence of this is unlikely but not exactly remote, so a 3 was scored. A 5 was given for detectability as many issues with heat draw would be subject to early detection by operator senses, i.e. lowering fan RPM, and increased PC heat, but it would still be possible that failure would occur seemingly spontaneously to the user. This gave a final rating of 75. Suggestions for intervention included more objective sensors such as core temperature and fan RPM sensors, as well as suggestions for procedural approaches to fan testing to ensure faulty fans are spotted early. Usage conditions were also introduced such as not running the device outside of a given temperature and air pressure range. A dust trap was also suggested for preventing physical airway obstruction.

Critical design features

In order to determine critical design features, a P diagram was constructed. This diagram (fig. 5) helped to identify sources of noise and track control factors in the functioning of the device.

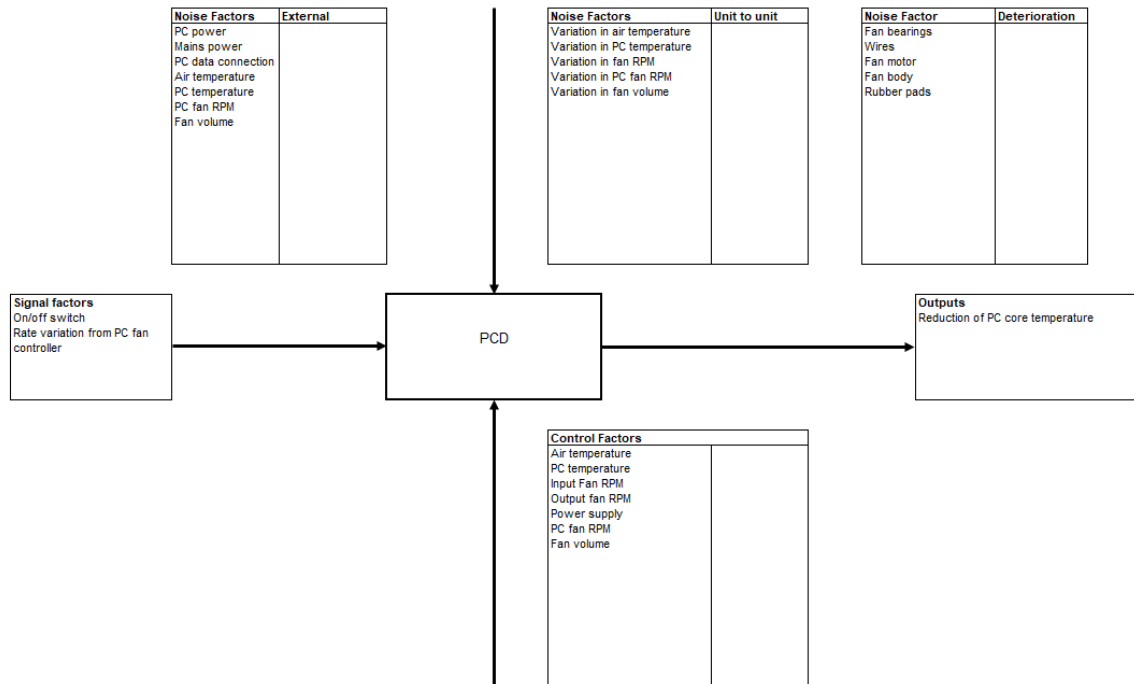


Fig. 5: P diagram presenting the noise and control factors present in the functioning of the device

These noise and control factors were then compared in a “what why” diagram and assigned relative weightings based on how much a noise factor affected a control factor. This helped to identify the which design features were critical because their functions could be related to the most impactful control factors (fig. 6).

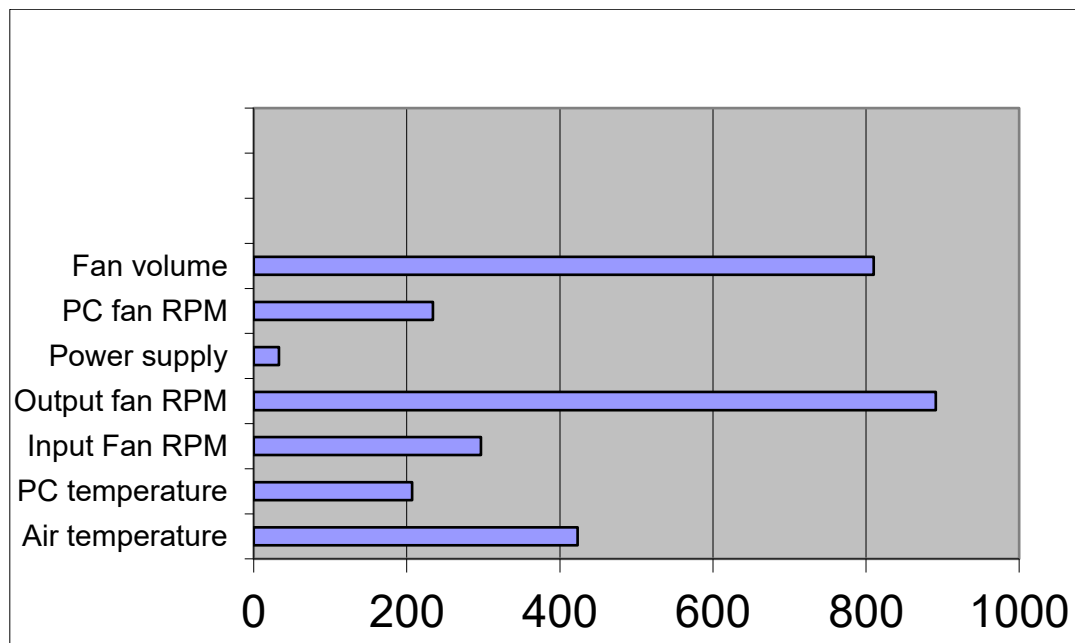


Fig. 6: Chart comparing the importance of control factors to inform critical design features

This indicates that fan RPM is by far the most impactful control factor, as it links to noise factors of PC temperature, fan parts health, power supply, air temperature and even PC

fan RPM. The least impactful control factor is power supply. While it would be expected that power is one of the most critical design features, power reliability is largely an external control factor and neither the operator nor designer can significantly affect it beyond establishing a minimum standard of power reliability.

Conclusion

In summary, the tools belonging to the QFD process helped to provide a more objective evaluation of individual differences between product features and functions, as well as guidance on how to prioritise requirements and functions during concept design selection especially in the case of the pair-wise comparison and Pugh matrix tools. The DFMEA tool provided useful guidance on where to prioritise failure interventions and would be an extremely effective tool in a resource limited environment. The P diagram and “what why” tools were helpful in establishing critical design features.

The V1 design concept would likely be an effective and superior replacement for the current implementation of a PCD and this is owed to the objective numerical approach outlined in the QFD process.

References

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Supplementary materials

The following pages are appendices containing additional context referenced in the main body of this report. Their addition is not intended to contribute to the word count due to their nature as tables.

Appendix A – Use case

Author: Conor Nolan		Date: 05/01/2026
Actors: PC owner (me). Any other PC operator.		
Pre-conditions: The PC is on The PC is running at high CPU and/or GPU temperature. Power is available via at least USB-A, if not 13A 3-pin main supply.		
Post-Conditions: The PC must be running at a lower temperature under the same usage conditions as prior. The user experience must not be significantly disrupted by noise, vibration or physical hindrance. The PC must retain full functionality, i.e. not broken or experiencing power issues		
Basic Flow: 5. The user interfaces the PCD with the PC, both physically and electronically. a. The PCD should physically integrate with the PC such that it does not significantly affect usage. b. PCD should connect electronically with the PC in any way appropriate for data or power transmission that might be needed. 6. The user turns the PCD on. a. The PCD should remain inactive until user direction is given via off/on switch. 7. The user operates PC as normal. a. The PCD should transfer heat away from the PC system at a rate faster than the heat accumulates. 8. The user may be able to adjust cooling power manually or automatically using software/hardware integration. a. The PCD must respond to software commands with changes in cooling power.		
Alternative Flow: 5. The user does not interface the PCD with the PC. a. The PCD will not cool the PC, but may function regardless if powered on. 6. The user does not turn on the PCD. a. The PCD will not function. 7. The user operates the PC beyond the bounds of normal use. a. While the PCD will cool, it may not be sufficiently powerful to dissipate the heat produced, resulting in possible PC or PCD damage. 8. The user gives inappropriate software commands to the PCD.		

- a. The PCD's software parameters should be bounded, such that any inappropriate commands return to a default parameter.

Exception Flow :- The things that can happen to prevent the user from reaching their goal.

- 5. The software or software/hardware integration fails to give appropriate commands.
 - a. If the software fails, the PC, PCD or user of both may be damaged due to heat or mechanical effects.
- 6. Power supply interference
 - a. The PCD may not function if power is required but not supplied.
- 7. Mechanical interference
 - a. If the PCD has mechanical operating principles, it may fail to cool sufficiently or at all, if mechanical issues such as wear and tear occur.
- 8. Environmental temperature interference
 - a. The PCD may fail to cool sufficiently or at all if the environmental temperature beyond a certain point, depending on the operating principles.

Appendix B – DFMEA

Function	Failure Mode	System effect	Effect Seen by user	Severity	Cause	Mechanism (If Known)	Occurrence	Detection / prevention method	Detectability	Rating	Suggested intervention
Interface hardware	No hardware connection	No adjustable fans	Fans only run at 1 speed	1	Poor contacting or breaking of conductors.	No electrical connection between PC and PCD	2	Ensure contact clean	5	10	Cover ports when not in use, introduce cleaning procedure
Interface supply	No power supply connection	Complete failure of electronic components	Fans not operating	5	Poor contacting or breaking of conductors.	No electrical connection between PC and PCD	2	Ensure contacts clean, strain and undamaged, general electrical housekeeping.	5	50	Cover ports when not in use, introduce cleaning procedure

Interface physically	No physical interface between PC and PCD	Diminished cooling capability	Higher PC core temperatures	2	Physical obstruction preventing correct placement or lacking friction on rubber pads.	PC is obstructed from being placed or slides off of platform	4	Ensure platform is clear and rubber pads are not worn.	1	8	Textured rubber will provide higher friction and aid in early detection of worn rubber. High contrast monotone colouring of platform will aid in detection of obstruction.
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Draw heat	Poor or no heat draw	Significantly diminished cooling capability	Higher PC core temperatures	5	Multicausal - electrical failure, mechanical failure, high ambient air temperature, low ambient air pressure, physical airway obstruction	Low flow rate air fails to transfer heat from inside the PC to outside and instead provides mild insulative effect.	3	Auditory detection as fans not heard, PC core temperature elevation will draw attention.	5	75	Introduce fan testing before operation, electrical temperature alert for high core temp as an early detection method. Outline usage conditions to exclude high temp or low pressure environments. High contrast colouring of airways and fans to show obstruction. Dust trap.
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Expel heat	Poor or no heat expulsion	Increase d local heat buildup and diminished cooling capability	Higher PC core temperatures and local environmental temperature	2	Multicausal - electrical failure, mechanical failure, high ambient air temperature, low ambient air pressure, physical airway obstruction	Low flow rate air fails to transfer heat from inside the PC to outside and instead provides mild insulative effect.	3	Auditory detection as fans not heard, PC core temperature and local temperature elevation will draw attention.	5	30	Introduce fan testing before operation, electrical temperature alert for high core temp as an early detection method. Outline usage conditions to exclude high temp or low pressure environments. High contrast colouring of airways and fans to show obstruction. Dust trap.
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Vary rate	No variation in fan RPM	No adjustable fans	Fans only run at 1 speed	1	Electrical failure including aberrant supply voltage, mechanical wear, poor lubrication or otherwise excessive friction.	Flow flow rate air fails to transfer heat from inside the PC to outside and instead provides mild insulative effect.	3	Fans may auditorily not change, indicating no RPM change, or may produce unusual noises consistent with fan failure. Software malfunction is likely detectable by PC.	5	15	Introduce fan testing before operation, digital temperature alert for high core temp as an early detection method.
Disconnect hardware	No hardware ejection	Stays live and does not compact	Stays assembled	2	Melting, welding or other catching of USB port	Physical inability to remove USB plug from socket	3	All causes have preindication such as high core temperature, resulting in	4	24	Port covers deployed when not in use to prevent debris build up in ports, temperature

								somewha t higher rates of detection.			detection alarms, choose high melting/we lding point materials for USB plug
Discon nect supply	No power supply ejectio n	Stays live and does not compac t	Stays assemble d	2	Melting, welding or other catching of USB port	Physical inability to remove USB plug from socket	3	All causes have preindicat ion such as high core temperat ure, resulting in somewha t higher rates of detection.	4	24	Port covers deployed when not in use to prevent debris build up in ports, temperatu re detection alarms, choose high melting/we lding point materials for USB plug

Separate physically	No PC ejection	Does not compact	Stays assembled	2	Melting, welding or other catching of PC on the PCD platform	Physical inability to remove PC from platform	2	All causes have preindication such as high core temperature, resulting in somewhat higher rates of detection.	4	16	Port covers deployed when not in use to prevent debris build up in ports, temperature detection alarms, choose high melting/welding point materials for USB plug
Pack up	Failure to compact	Does not compact	Does not fit in bag	2	Material/mechanical faults in cables or adjustable legs producing obstruction	Parts obstruct each other from packing into bag	3	Will be visually or practically detected up packing up procedure	1	6	Individual packaging may aid in overall compactability

Manage volume	Volume increases beyond tolerable threshold	Increase d volume and vibration	PCD is too loud	2	Excessive friction or movement of loose parts, or increased fan RPM	Moving parts produce high intensity sound waves which reach the user through gases.	5	Auditory early detection by the operator is expected and fan RPM can be adjusted	3	30	Decibel meter can be attached to detect excessive volume and reduce fan RPM, bearings and part tolerances can be held to strict levels
Manage vibration	Vibration increases beyond tolerable threshold	Increase d volume and vibration	PCD is too loud	2	Excessive friction or movement of loose parts, or increased fan RPM	Moving parts produce high intensity sound waves which reach the user through solids.	5	Touch early detection by the operator is expected and fan RPM can be adjusted	3	30	Decibel meter can be attached to detect excessive volume and reduce fan RPM, bearings and part tolerances

											can be held to strict levels
Prevent electric shock	Operator is shocked	Power interruption and potential component damage	Injury due to shock	4	Incidental contact between operator facing conductors, otherwise poor insulation, significant overcurrent and/or aberrant voltage spike	Current flows from PCD to operator to ground/circuit	2	RCD protection detects and cuts off residual earth currents, circuit breakers detect and prevent overcurrent, surge protection prevents transient over-voltage. Extra low voltage supply	1	8	Could consider class 2 insulation or SELV supply for extra safety

								from PC. Earth bonding of external metal compone nts			
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