MITSUBISHI ELECTRIC
Changes for the Better

The Art of Noise Reduction

The impact of noise reduction in high-speed hand dryers

Preface:

Hand dryers are convenient to use and compared with fabric or paper towel alternatives - relatively cheap and easy to maintain and operate from a facilities management point of view. The environmental impact in terms of energy use and the sustainability of resources, it can be argued are also much lower than disposable or washable alternatives. However, the human built environment is an ever-changing place and the more we learn about it and its effect on the inhabitants, the more we realise that noise pollution has a negative effect on every part of our daily life.

Most countries have legislation in place designed to control the build-up of ambient noise in the workplace and other public buildings. While this was initially developed at national levels, over time many countries have brought their legislation into line with one another. Thus requirements are similar across say the European Union and other regions, where there is general health and safety legislation that sets expectations and ground rules, plus specific legislation relating to noise control as well other areas such as fire safety, atmospheric conditions and the handling on dangerous substances or heavy loads.

For instance, in the United Kingdom the Control of Noise at Work Regulations 2005 place a duty on employers to reduce the risk to their employees' health by controlling the noise levels in their premises. The regulations were established under the Health and Safety at Work etc. Act 1974 and implement European Council directive 2003/10/EC.

What exactly is the impact of noise created by electric hand dryers and can it be reduced?

This study looks to assess the impact and establish where the operating parameters of some products can reduce environmental noise, to the benefit of users, and the requirement of some places where quietness is a necessity due to the function of that facility.

Contents.

Chapter 1 - Background

1.1 Introduction

Hand washing is a fundamental requirement in personal hygiene, which means so is hand drying. Public bathrooms therefore must be equipped with hand washing and drying facilities. There are several options for drying, including some modern high-tech solutions that address multiple needs beyond simply hand drying. All of which have an environmental impact.

The modern form of public bathroom probably began to evolve 100-150 years ago, at which point hand drying was almost certainly based on the use of a domestic-style towel. However, with multiple uses such towels will have quickly become wet, ineffective, unhygienic and unpleasant to use.

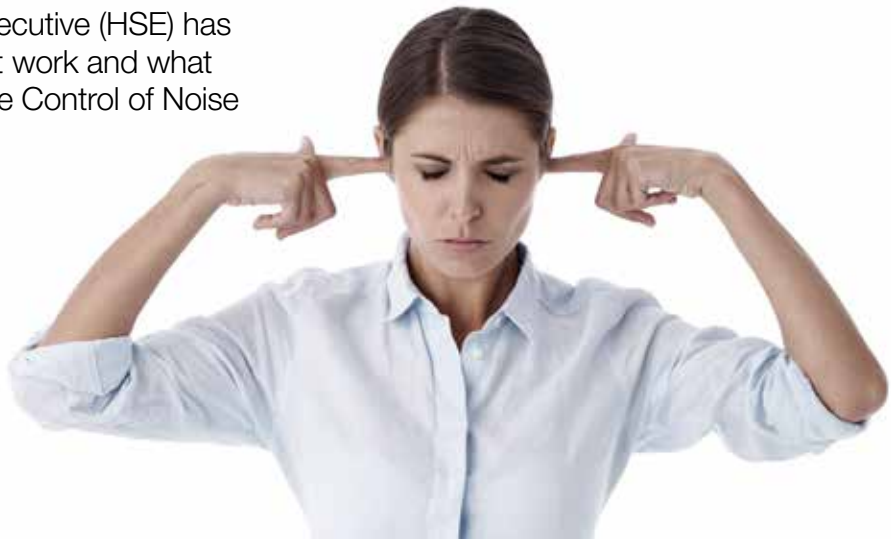
This led to the development of the long-length roller towel which was supplied in a ratcheted unwind and rewind dispenser. In use, each successive user can pull out a clean, dry length of towel on which to dry their hands. This was a major step forward in terms of public health, but meant a janitor had to regularly replace used rolls with fresh ones and it also created a need for a specialist laundry service.

1.2 Legislating for noise control

Fifty or sixty years ago very few countries had safety regulations relating to workplaces, but they began to be developed in the second half of the 20th century. Each new law or standard covered a different aspect of safety, so the overall effect was at first somewhat piecemeal. Co-ordination of the regulations began in the 1970s with the introduction of legislation such as the UK's Health & Safety at Work Act 1974.

The Control of Noise at Work Regulations 2005 place a duty on employers and premises owners in Britain to reduce the risk to people's health by controlling the noise they are exposed to. Most regions of the world now have similar laws.

The UK's Health & Safety Executive (HSE) has published a guide to noise at work and what employers must do under the Control of Noise at Work Regulations 2005.



Most laws and standards relate to noise emanating from individual pieces of equipment and machinery. Additionally, Part E of the UK Building regulations specifies details of sound proofing requirements designed to prevent noise propagation from room to room.

1.3 Technology based solutions

During the 1960s alternatives to the roller towel began to become popular, including the hot air hand dryer and disposable paper towel.

Hot air dryers never ran out and needed little by way of service support, thus were considerably cheaper to run than roller towels. However, they consumed electricity, had the effect of blowing potentially bacteria-laden moisture around the bathroom, and could cause water to drip onto the floor.

The main issue for users was the length of time it took for the heater element to warm-up and hence the time-period required to dry the user's hands.

They are also very noisy, something that has been ignored by many manufacturers to this day.

Paper towels did away with the need for laundry but created a large amount of waste that had to be disposed of. Also, the dispensers needed regular repairs, replacements, monitoring and frequently topping up by a janitor or other service person.

In the 1960s the consumption of electricity and the creation and disposal of waste paper was of little concern to most people. However, these attitudes were to change significantly over time with rising energy costs and increasing awareness of wider environmental issues.

1.4 A contemporary approach

By the 1980s hot air hand dryers had become the norm and were fitted in most public bathrooms in preference to roller towels. Paper towels were a favoured solution where electricity was not available and where the noise of a hot air dryer was deemed to be unsuitable, such as in theatres, libraries, medical wards and conference centres.

However, attitudes were changing and issues that worked against these two hand drying solutions were coming to the fore. For instance, financial accounting practices were improving and began quantifying individual elements of overhead costs. As such the cost of hand drying was being assessed in detail. (In fact, as well as coming under more scrutiny, prices relating to electricity, paper towels and janitorial staff were also increasing).

Greater concern for hygiene was also developing within the general public, while operators of public bathrooms were becoming increasingly aware of their duty of care.

Development work started on some new ideas and 1993 saw the launch of a new style of hand dryer, the ‘high-speed air-curtain hand dryer’, developed by Mitsubishi Electric. Originally introduced in Japan under the name of Wave, they proved immediately popular and the manufacturer found domestic demand alone taking up most of its initial production capacity. As a result, international promotion and distribution of these innovative hand dryers did not start in earnest until some years later.

Further, the manufacturer was aware that, as with all new technologies, there were several possible further developments and refinements to be explored. First, high-speed warm hand dryers were developed. Subsequently, the high-speed air-curtain hand dryer rapidly went through a development cycle in which different aspects of performance were each incrementally improved.

Chapter 2 - High-speed air-curtain hand dryers

2.1 Basic concept

Warm air and warm air high-speed hand dryers work by creating a relatively large envelope of hot air, in which wet hands are held so that the moisture on them warms up and evaporates. A lot of energy is required to create and maintain this hot air bubble and drying times are relatively long (about 30 seconds).

Development engineers working on electric hand dryers were looking to reduce both the energy consumption and the drying time, both of which would help reduce running costs. It was also thought that reduced drying time would discourage the common, but unhygienic, practise of walking away with only partially dried hands.

2.2 Initial design and development

Many of the designers working on the new hand dryers had a background in manufacturing. As such they were familiar with a common piece of factory equipment, the air knife. These create a curtain of high-speed air that is often used to dry products passing through it on a conveyor belt. They are also used for other duties, such as wiping away excess paint, applying heat, washing and even for cutting or breaking up solid materials.

The engineers soon wondered if a variation on the industrial air knife could be used to dry peoples' hands. Some simple experiments showed that they did indeed work something like a form-hugging squeegee and were very effective at 'wiping' moisture off hands placed in their airflow. A hand briefly held in an air curtain was dried on both sides and between the fingers in approximately half the time required by warm air hand dryers, typically about 15 seconds, and with no discomfort or other effect.

A series of measurements and calculations established that a relatively small air flow was needed to wipe off adult-sized hands, so it was then only a matter of redesigning the industrial air knife for its new duty and working environment.

2.3 Refining the design

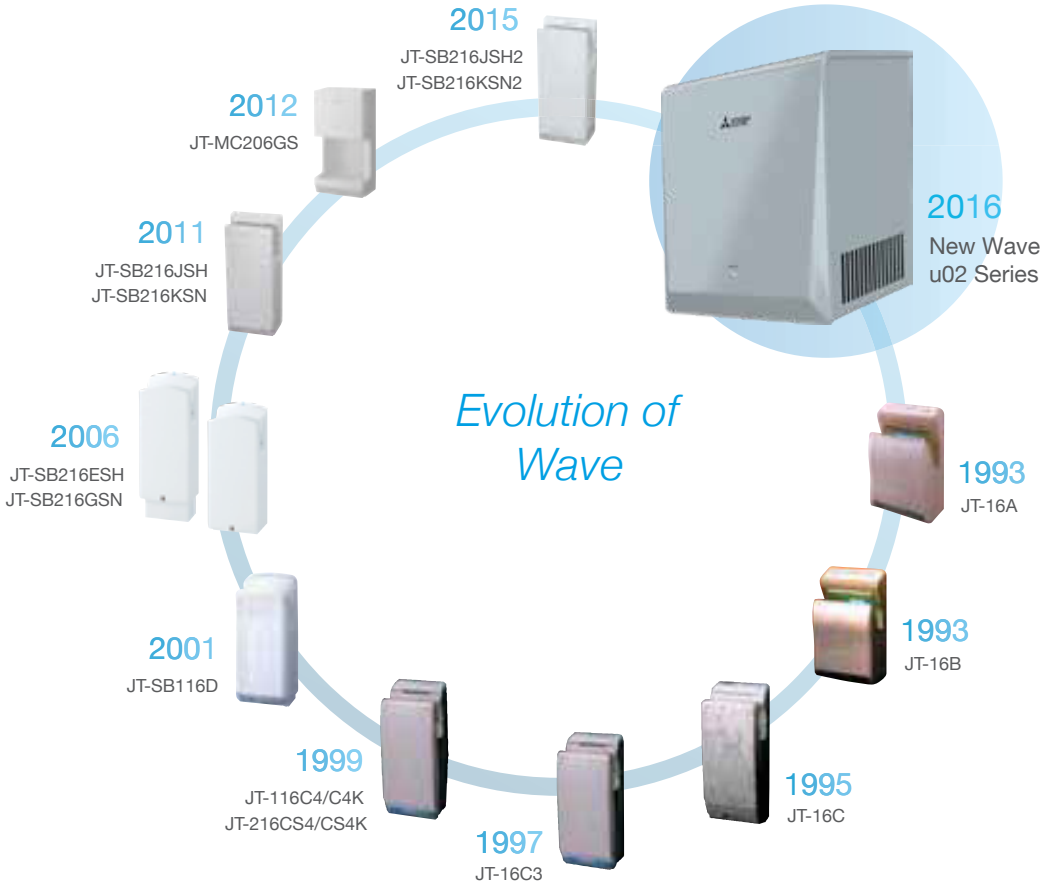
Industrial air knives are designed to be robust enough to withstand the rigour of the factory floor and to be large and flexible enough to work with significantly different products. Redesigning them for use in bathrooms and dedicated to the single duty of hand-drying meant some cosmetic changes, but also allowed the design to be optimised to a very large degree – including the adoption of a fan / motor sized designed and optimised for one single purpose.

The result of this focus on the fan and motor design was that an energy saving of about 90 percent was achieved compared to a traditional warm air hand dryer, while tests showed that drying time was cut by approximately 50 percent.

2.4 Unexpected benefits

As design and development work proceeded additional advantages began to become apparent. For instance, it was realised that the liquid moisture coming off the hands was very much more controllable than the gaseous evaporant generated by warm air hand dryers. This meant it could be collected efficiently and disposed of hygienically, rather than having it float around the bathroom to re-condense on cold surfaces such as door handles – where it could potentially aid the transfer bacteria from person to person.

Another advantage was that the new high-speed air-curtain hand dryers were quieter than warm air high-speed hand dryers - and this was initially without the designers even considering the noise output. It did not take the development team long to bring some acoustic experts on board to look at analysing what noise generation there was and seeing if there were ways to make operation even quieter. Despite their good drying effectiveness, these first high-speed air-curtain hand dryers were still relatively loud emitting about 71dB. However, one of the first things the experts pointed out was that as the operating time was only one-half that of older dryers, noise was created for a significantly shorter time so would be proportionally less annoying! Nonetheless, thorough design and noise reduction techniques could reduce the noise level generated by high-speed air-curtain hand dryers.



Chapter 3 - Noise Reduction

3.1 Continuous development

Very few products arrive on the market in a perfect design. Most are introduced in a functional and commercially viable form then refined in a series of steps until they reach a mature design stage.

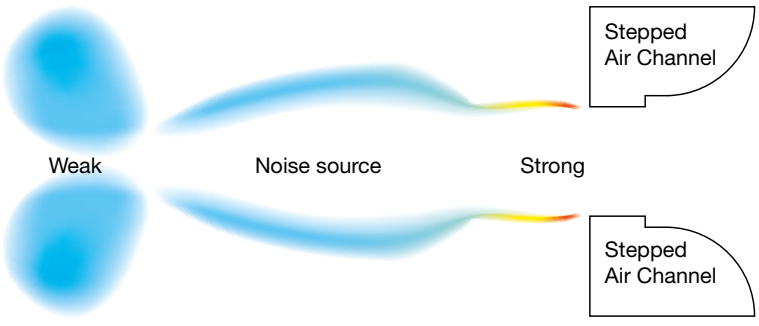
Mitsubishi Electric subjected its high-speed air-curtain hand dryers to this constant improvement, as a result of which today's models are very different from those originally launched back in the 1990s. They have been improved on many fronts, including energy efficiency, bacterial control, aesthetics and – the focus of this study - noise reduction.

3.2 Noise signature

From the earliest days it was recognised that Mitsubishi Electric high-speed air-curtain hand dryers were going to be a quiet option compared to warm air high-speed hand dryers. There were several factors contributing to this.

- Less air needed to be displaced. A warm air high-speed hand dryer works by maintaining a relatively large three-dimensional envelope of hot air. A high-speed hand dryer creates an effectively two-dimensional curtain of air, thus there is very much less air in motion.
- Laminar versus turbulent air flow. In an air curtain all the air is flowing in the same direction and at approximately the same speed, in an orderly manner. A hot air envelop, by contrast, has a relatively large volume of very turbulent air, with different flows intersecting and colliding and thus creating noise.
- The lower air flow means that inlets and outlets can be smaller, thus any generated noise has less opportunity to escape from the body of the dryer
- The lower air flow of a high-speed air-curtain hand dryer means a smaller motor can be used than in a traditional dryer. In use this will create less noise because the rotating parts are smaller, displacing less air.

Thus, it is to be expected that high-speed air-curtain hand dryers should be quieter than their traditional counterparts.



3.3 Further noise reductions

Once it was realised that high-speed air-curtain hand dryers had unprecedented drying effectiveness but were still loud during operation, the original design team at Mitsubishi Electric took up further noise reduction as a theme. To this end they were careful to select a motor that was optimally sized and efficient for the job in hand, thus extra power (and associated noise) was not generated. Further, the short drying time meant the motor was running for the minimum duration.

They also designed motor mountings that absorbed vibration and thus reduced noise transmission through the solid frame of the dryer and used sound deadening materials for the casing. Other similar measures and design details were also adopted. They also located the motor deep in the body of the dryer for maximum shielding.

Thus, even early models of high-speed air-curtain hand dryers were quiet in operation. In fact, they were so quiet that they quickly re-defined user expectations and market standards. Mitsubishi Electric high-speed air-curtain hand dryers, known as Wave, were immediately recognised as the go-to dryers for noise sensitive installations.

3.4 Even more noise reductions

As noted earlier, very few technologies arrive on the market fully developed. So, it was with noise control in high-speed air-curtain hand dryers. Each successive new generation of Mitsubishi Electric Wave has become quieter, with new details incorporated to reduce noise that little bit more.

Today's latest, ninth generation, Wave high-speed air-curtain hand dryers have new features that each contribute their own little bit to noise abatement, with the end result being market leading whisper quiet levels of operational noise.

Chapter 4 - State of the art sound reduction

4.1 Latest techniques

Mitsubishi Electric Waves are among the most advanced high-speed air-curtain hand dryers available on the market today, and incorporate a plethora of noise management features, including the ones Mitsubishi Electric established and have been in use with earlier models as well as innovative new ones based on advanced acoustic analysis conducted at Mitsubishi Electric.

Wave high-speed air-curtain dryers are now available in two formats, the original 'hands-in' style where wet hands are placed in a generously-sized chamber or slot in the top of the unit, and the 'hands-under' style similar to a conventional warm air hand dryer. The new sound reducing features of 'Wave hands-in' i01 model and 'hands-under' u02 model high-speed air-curtain hand dryers include:

- The source of most of the noise in a hand dryer is the fan and motor or 'blower' unit. Mitsubishi Electric's most advanced high-speed air-curtain dryers now use a long air duct that is deliberately shaped to create a twisting air passage. This has the effect of reducing the amount of noise escaping from the motor. As a secondary benefit, a C-Shaped bend near the free end of the duct also prevents water from working its way into the body of the dryer.
- In the Mitsubishi Electric design, the air flows through a dust filter, which traps dust, pollen and other particulates and also absorbs motor noise.
- The motor compartment in Wave models is designed to absorb sound and to deaden vibrations so that noise is not transmitted to the wider environment.
- The outer casing is also made up of robust, strong and durable body panels that absorb sound rather than transmit it.

With Wave i01 'hands-in' units, the two high-speed air curtains partially collide, creating some noise. In addition, the air flowing into the top of the drying chamber exits out the sides. This requires a change of direction, which could create noisy turbulence. Therefore, two additional noise reduction features are present in 'hands-in' high-speed air-curtain dryers:

- The airflow nozzles the direct drying air onto the user's hand are shaped and positioned for minimised noise emissions, *see 4.2 Outlet nozzles* below.
- An air flow directing silencer is fitted in the drying chamber, *see 4.3 In-chamber silencer* below.

4.2 Outlet nozzles

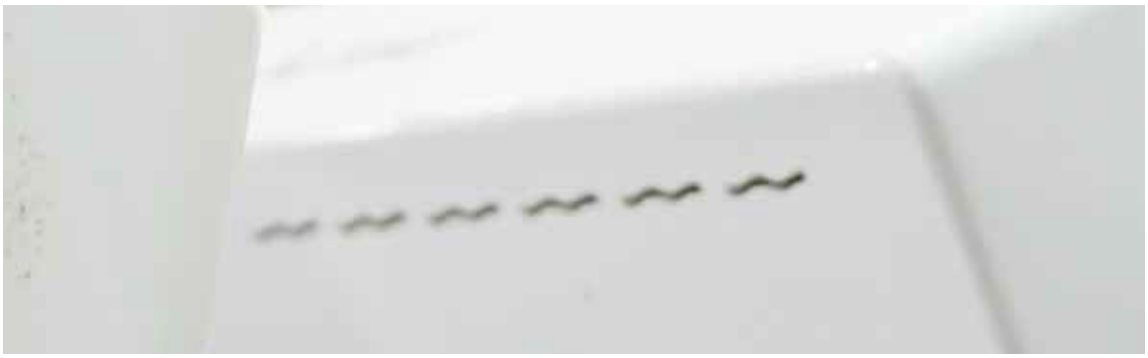
Original warm air hand dryers had only the simplest of outlet air nozzles, their main role being to protect the end of the air duct rather than to control the airflow. As the airflow was relatively low speed and the duct a relatively large diameter, a nozzle would have had very limited effect in direction and shaping air flow. However, some models of warm air hand dryer are fitted with a rotating direction nozzle so that the warm air can be routed upwards towards the user's face, to aid drying-off of rain water etc.

In contrast the use of air outlet nozzles is fundamental to high-speed air-curtain hand dryers. Essentially to create a laminar flowing air curtain a long, thin slit-shaped nozzle is required. In practice this is often created as a line of shorter slit nozzles so that the structural integrity of the panel containing the nozzles is maintained.

This is how the original Wave high-speed air-curtain hand dryers were supplied. The arrangement created an effective air curtain that was very efficient at wiping moisture from hands. The design team realised that the nozzles created a degree of noise. Therefore, Mitsubishi Electric engineers wanted to review this aspect of jet air design with the ambition of reducing noise levels further.

When acoustic specialists began to look at redesigning the Wave nozzles to reduce noise creation, they decided to change the nozzles from straight line slits to wave shaped slits. This had a noise reducing effect because the curves reduced the edges generated by straight nozzles, cutting the noise level by a significant 1dB.

In fact, the wave shaped nozzles in Mitsubishi Electric Wave i01 were introduced in 2011 and further refined in 2015. This time the shape of the airflow passage behind the nozzle was fully optimised, a step that took another 2dB off the noise levels.



Wave shaped nozzles reduce noise

4.3 In-chamber silencer

From the earliest days of the original Wave high-speed air-curtain hand dryers, the designers used acoustic analysis to profile the overall shape of the chamber to minimise turbulence and therefore extraneous noise. (It is notable that some manufacturers of high-speed air-curtain hand dryers have not followed this lead, so their drying chambers do not have a noise reducing geometry and may even act as amplifiers.)

In 2015 there was a second noise reduction innovation in the form of a small triangular flow detector built into the centre of the bottom of the drying chamber. This has the effect of directing half the air flow out of the right-hand side of the chamber and the rest to the left. This lowered air turbulence in the chamber below the hands significantly and thus led to a notable noise reduction.

The size and location of the deflector is such that it does not interfere with the movement of the user's hands at all.

Triangular flow deflector reduces noise

Chapter 5 - Measuring noise intensity

5.1 How quiet is quiet?

Sound levels are measured in decibels or dB. This is a logarithmic scale, rather than linear, so goes up in powers of ten: every increase of 10dB on the scale is equivalent to a 10-fold increase in sound intensity. To get an idea of what this means, 0dB is the quietest sound audible to a human ear. From there, every increase of 3dB represents a 100 percent increase in sound intensity perceived, or acoustic power. Sixty decibels equate to the noise level of a normal conversation.

5.2 How quiet are Wave hand dryers?

Looking at high-speed air-curtain hand dryers, the noise output of the Mitsubishi Electric Wave, generation 9 is measured as 56dB in standard mode, which means the operational noise level is little more than half that of normal conversation. By comparison, a competitor product, the Dyson's Airblade V, tested at 63dB of noise[1], 200 percent louder than normal speech or approx. 400 percent as much as a Wave.

While Wave is probably the quietest high-speed air-curtain hand dryer on the market, Airblade may not be the loudest (unsurprisingly manufacturers who find their dryers to be loud tend not to publish acoustic performance data)!

From this we can conclude that while some high-speed air-curtain hand dryers are very quiet and therefore suitable for use in noise sensitive installations, others are not. In fact, some makes of high-speed air-curtain or warm air hand dryers may be so noisy that they should not be used in large installations where a high throughput of users would require a bank of multiple dryers. In the worst case, noisy dryers should be confined to areas where noise is not a problem.

5.3 Measuring noise

Sound decays with distance from its source, so the level of noise recorded on a sound level meter will vary according to the relative positions of the source and meter. Thus, when measuring noise for purposes of comparison or for establishing standards, consistent distances must be used. Further consideration also must be given to nearby surfaces that could reflect extra sound onto the meter.

In the case of hand dryers, the height the meter is above the floor of the installation, be it a bathroom or a test laboratory, will need to be consistent. All test-piece dryers will be mounted on a back wall, which will have a consistent effect on meter readings. However, in a 'real world' bathroom there will be other nearby walls that may deflect extra sound onto the meter (such walls would not be simulated in a laboratory-based test).

(It is notable that bathroom walls tend to be hard surfaces that are easily washed down to maintain hygiene, but which are also highly reflective of sound waves.)

[1]Dyson. Dyson Airblade V. Low voltage and high voltage technical specifications.
Available at: http://www.handdryersupply.com/content/dyson-airblade-v-hu02-spec.pdf. [Accessed: 31.01.2018]

5.4 One manufacturer's approach

To maintain this ever-advancing march of technology, Mitsubishi Electric, which developed the original high-speed air-curtain hand dryer, has to be scrupulous in measuring and monitoring performance levels, including in the noise emissions. To this end it has standardised on consistent measuring procedures that reflect real-world installations.

It measures the noise output of its hand dryers in an anechoic chamber, which while about as dissimilar from a public bath room as it is possible to get, allows the dryers' noise output to be totally isolated from other noises so that measurements are of that and that alone. However, they are mounted in a realistic manner, which is to say on a solid wall that will reflect very nearly all sound forwards towards the sound level meter. Both models are mounted at the same height as they would be in 'real life', i.e. for a Wave i01 the bottom of the drying chamber is 0.7m above floor level, while Wave u02s are mounted so that their centre is 1.2m above the ground.

In both cases the sound level meter is mounted 2m forward from the dryer. While users would stand much closer to the dryer, the 2m distance ensures a consistent and stable characteristic to the sound waves and provides the researchers and lab technicians with sufficient room to move around without disrupting equipment.

The dryers, like nearly all equipment, do not produce a pure single sound, but a noise 'signature' made up of several different frequencies. Mitsubishi therefore measures the sound levels at several different frequencies and combines these to analyse the signature.

> For the 'hands-in' i01, the lowest sound frequency measured is 62.5Hz, which registered at 19.7dB. This increased to 53.9dB at 4000Hz, after which the decibel level declined rapidly.

Corresponding figures for the u02 'hands under' were: 25dB at 62.5Hz and 59dB at 4000Hz.

Full profile figures are given in Appendix 1 and 2 respectively.

Mitsubishi also conducted a second test on the Wave i01, in which the sound pressure level was measured rather than the sound intensity level. Readings were taken 2m in front of the dryer, and 2m to the left and 2m to the right, in line with the open sides of the drying chamber. The results were consistent with the sound intensity measurements, with full figures given in Appendix 3.

5.5 Further considerations on noise analysis

Noise can be defined as ‘sound that is in some way annoying to a person or persons hearing it’. Thus, identifying the annoying components of a sound signature allows reduction in the perceived noise level. It is worth noting that while there is a level of subjectivity to what different sounds individuals find annoying, there are consistent patterns that apply to large numbers of people.

For instance, certain frequencies, usually higher pitched ones, can be very irritating and create feelings akin to earache or tinnitus, while low pitched sounds tend to be ‘felt’ in the lower torso or pit of the stomach and can lead to feelings of nausea.

Mitsubishi Electric tries to design their products so that they do not include such frequencies in their sound signature. This can be done by sound deadening techniques, air flow manipulation and by changing the mass of components that transmits sound.

A variation of this phenomenon is seen when certain frequencies or sound patterns are heard together and create an annoying effect. Again, Mitsubishi Electric identified such problems in prototype products and design them out.

In recent years acoustic specialists have developed active noise cancellation techniques. The principle behind this is to identify the frequencies within an annoying sound signature and generate reciprocal wave patterns so that peaks cancel out troughs and vice versa. In some cases, this can be done by reflecting the sound waves back onto themselves 180deg out of synchronisation, in other cases secondary, out of sync, waves are generated.

Chapter 6 - Reality check: Proving Mitsubishi Electric Wave hand dryers are quiet

6.1 A quiet revolution in hand drying

The Mitsubishi Electric Waves i01 and u02 are the quietest dryer in their class, with an operating sound level of 56-60dB, while most of their competitors exceed twice this level. (The decibel level is logarithmic rather than linear, with noise intensity doubling every three decibels). Further, the Waves do not produce the high and low frequency sounds that can be particularly irritating to people.

Acoustic experts say that because most washrooms have hard-surfaced walls, floors and ceilings, echoing and reverberation make noisy hand dryers seem even louder than they are. While this is annoying to everyone, it can be particularly troublesome to vulnerable groups such as the elderly, dementia sufferers, young children and hearing-aid users.

In contrast, developers at Mitsubishi Electric have worked hard to minimise the Waves' sound signature, reducing the overall noise level and designing out the extreme frequency sounds that can be so penetrating.

A beneficial side-effect of this effort is to enhance Mitsubishi Electric Waves' energy efficiency – one way to reduce noise is to use insulation to muffle it; a better way is not to create the noise in the first place! Mitsubishi Electric went down the latter route and because it takes energy to create extraneous noise, there was an instant energy saving. In fact, because the drying chamber and air nozzles are so well-designed, the Waves are not only quiet, they are also able to use a more energy efficient motor.

Because of their minimal acoustics, Mitsubishi Electric Waves have become the hand dryers of choice in many sound-sensitive locations. They are installed in stately homes, business and conference centres, council chambers, universities, libraries, hospitals, hotels and the residential houses of several leading private schools.

6.2 Hospitality industry example

An East Anglian hotel has installed Mitsubishi Electric Wave hand dryers as part of a recent redecoration and refurbishment project. The project included a makeover for the public restrooms, which many hoteliers refer to as their most important rooms. As the refit neared completion, it became apparent that the sound of the hand dryers in the Ladies' restroom carried out into the lobby. This was intrusive; the volume and intermittent nature of the noise all seemed to add up to something slightly disturbing, which led to a quest to find the quietest hand dryer. The Mitsubishi Electric Wave, which produces effectively no motor noise, only a gentle air-rush sound, won the day.

6.3 Education establishments

Several primary schools have adopted Mitsubishi Electric Waves, mainly because they are quiet, but also because they dry hands fast enough for busy children and they minimise bacterial transfer. Boarding schools like Waves in their 'houses' or residential buildings, so that if a student rises in the night to visit the bathroom, the hand dryer does not wake the rest of their colleagues.

Waves have been installed at Oxford University's world-famous Bodleian Library, and in many other seats of learning and research around the world. Read more: wave.mitsubishielectric.co.uk/case-studies

6.4 Vulnerable people

Mental health charities in London and Brighton have installed Mitsubishi Electric Waves because their quiet operation does not disturb the calm atmosphere they try to create for their clients. Similarly, several police stations and courts of justice have adopted quiet Waves to help maintain calm and dignified atmospheres.

6.5 Aiding concentration

A council conference centre in Aylesbury, UK selected the Mitsubishi Electric Wave for its quiet operation and was delighted to realise that its short drying time reduced queuing during conference breaks when many delegates would head to the bathroom simultaneously. Similarly, theatre and cinema managers are increasingly appreciating the low noise Wave hand dryers – and with large numbers of users, their energy saving motors soon make a very welcome contribution to their balance sheets.

References

1. *Health & Safety at Work Act 1974*. UK. A framework for coordinating legislation regulations and standards in UK workplace.
2. *Control of Noise at Work Regulations 2005. UK*. . Specific noise control regulations for the UK. Developed with the European Union and likely to remain in place after Brexit.
3. *The Health & Safety Executive, UK*. The Health and Safety Executive (HSE) is the national independent watchdog for work-related health, safety and illness. It acts in the public interest to reduce work-related death and serious injury across Great Britain's workplaces. HSE is an executive non-departmental public body, sponsored by the Department for Work and Pensions.
   http://www.hse.gov.uk/
4. *The European Agency for Health & Safety at Work*. EU-OSHA is the European Union information agency for occupational safety and health. It contributes to the European Commission's Strategic Framework for Safety and Health at work 2014-2020 and other relevant EU strategies and programmes, such as Europe 2020.
   https://osha.europa.eu/en/safety-and-health-legislation
5. *Department of Labor, USA* Various Various Department of Labor (DOL) agencies have responsibility for the administration and enforcement of the laws enacted to protect the safety and health of workers in America. Hand dryers are covered by the Occupational Safety and Health Administration.
   https://www.dol.gov/general/topic/safety-health

Acknowledgments

1. Aston University
2. Aylesbury Council Buckinghamshire
3. Bodleian Library, Oxford University
4. Breckland Hotel, Norfolk
5. Department for Work and Pensions UK
6. Department of Labor, USA
7. Highgate Primary School, Loughborough
8. Mitsubishi Electric Japan
9. Mitsubishi Electric UK
10. Officers' Mess, Duxford

The authors would like to thank the following for providing information that has been used in this report

11. The European Agency for Health & Safety at Work
12. The Health & Safety Executive, UK
13. The National Trust, Stourbridge

Appendix 1:

N16JTGT0002

MITSUBISHI ELECTRIC Wave Technical Documentation	Subject	NC (Noise Criteria) Curves of Wave	Date	12 Jan 2016
	Model	JT-SB216JSH2-NE、JT-SB216KSN2-NE	Written	S.Nishimura
	No.	N16JTGT0002	Reviewed	M.Fukano

1. Conditions

a. Measurement Site : Anehoic room

b. Measurement Point : Shown by Fig.1

c. Power Supply : AC230V

d. Air Speed Mode : High

e. Weighting Filter : Flat frequency weighting

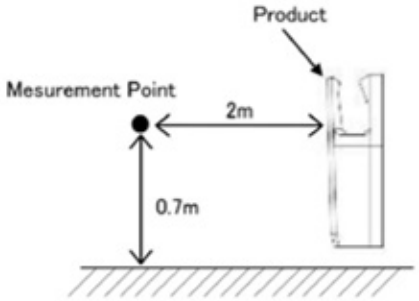


Fig.1

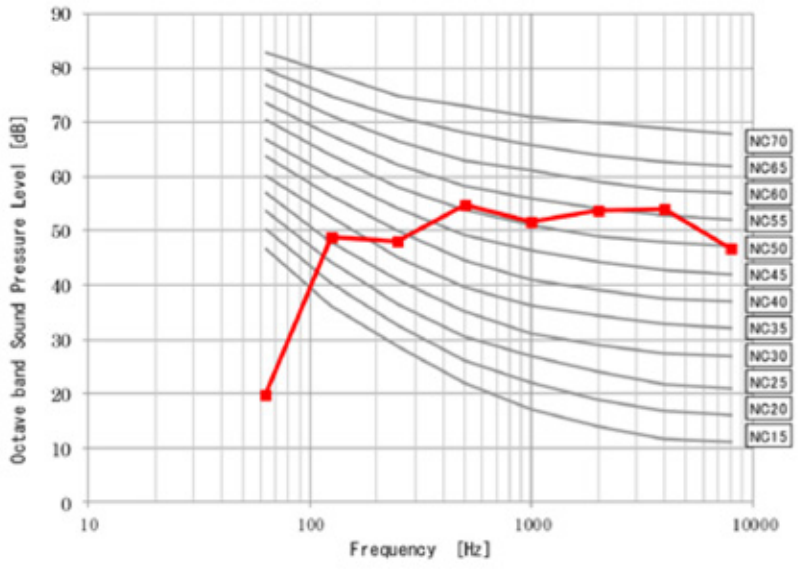
2. Results

a. Sound levels

Octave band center frequency	[Hz]	62.5	125	250	500	1000	2000	4000	8000
230V	[dB]	19.7	48.7	48.1	54.9	51.8	53.6	53.9	46.7

b. NC value and curves

Octave band center frequency	[Hz]	62.5	125	250	500	1000	2000	4000	8000
230V	[NC]	<15	30.8	38.1	51.1	50.8	54.6	56.2	49.7



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Appendix 2:

N16JTGT0001

MITSUBISHI ELECTRIC Wave Technical Documentation	Subject	NC (Noise Criteria) Curves of Wave	Date	12 Jan 2016
	Model	JT-S2AP、JT-S2A	Written	S.Nishimura
	No.	N16JTGT0001	Reviewed	M.Fukano

1. Conditions

a. Measurement Site : Anehoic room

b. Measurement Point : Shown by Fig.1

c. Power Supply : AC220V-240V

d. Air Speed Mode : High

e. Weighting Filter : Flat frequency weighting

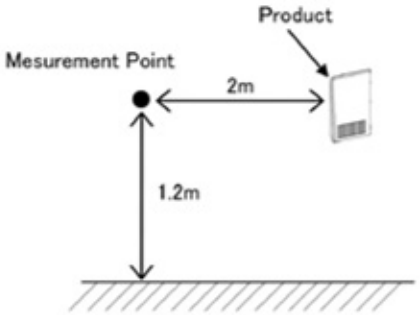


Fig.1

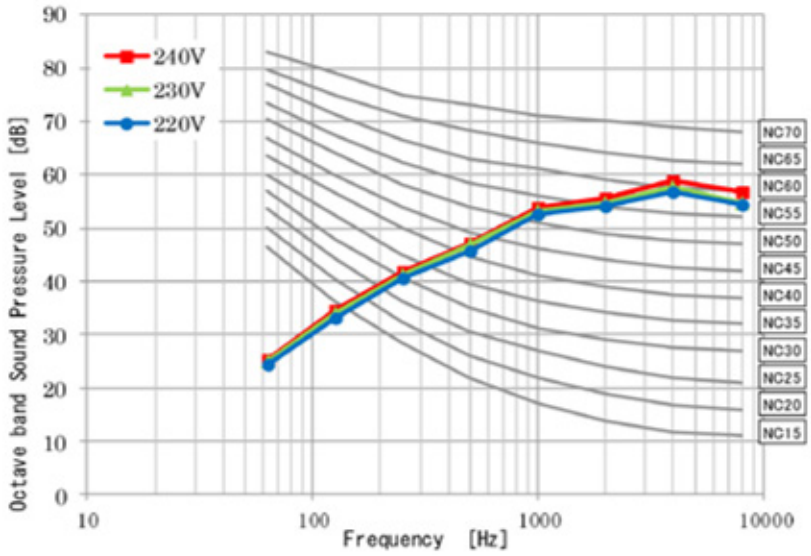
2. Results

a. Sound levels

Octave band center frequency	[Hz]	62.5	125	250	500	1000	2000	4000	8000
240V	[dB]	25.3	34.6	41.8	47.1	53.7	55.5	59.0	56.7
230V	[dB]	25.2	34.1	41.2	47.0	53.1	54.8	57.6	54.7
220V	[dB]	24.4	33.2	40.5	45.8	52.6	54.2	56.9	54.5

b. NC value and curves

Octave band center frequency	[Hz]	62.5	125	250	500	1000	2000	4000	8000
240V	[NC]	<15	<15	31.1	42.8	52.7	56.5	61.5	59.7
230V	[NC]	<15	<15	30.3	42.6	52.1	55.8	60.1	57.7
220V	[NC]	<15	<15	29.6	41.4	51.6	55.2	59.4	57.5



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Appendix 3:

N16JTGT0003

MITSUBISHI ELECTRIC Wave Technical Documentation	Subject	Sound pressure level mesuring method	Date	13 Jan 2016
	Model	Wave	Written	S.Nishimura
	No.	N16JTGT0003	Reviewed	M.Fukano

Conditions

a. Measurement Site : Anehoic room

b. Measurement Point : Shown by Fig.1

c. Sound Level Meter : Ordinary sound level meter

d. Frequency Range : 0～10kHz

d. Weighting Filter : A-weighted sound pressure level

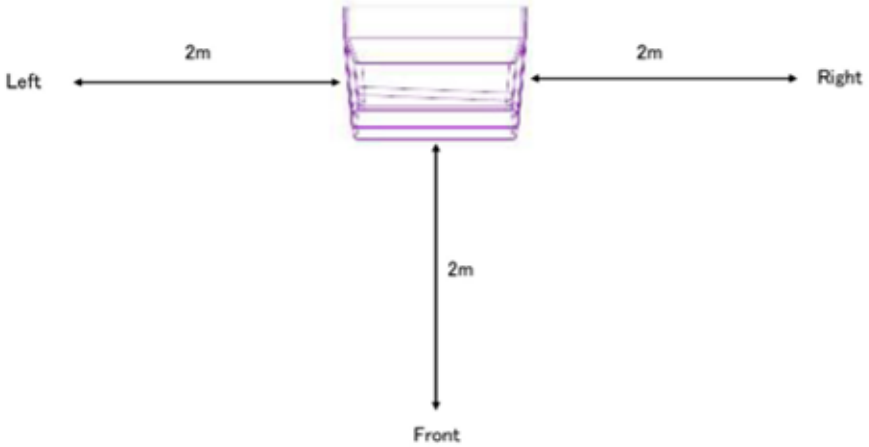

Fig.1

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Hatfield Headquarters Contact: Mitsubishi Electric Europe B.V., Automation Systems Divisions, Travellers Lane, Hatfield, Hertfordshire AL10 8XB
Tel: +44 (0) 1707 288769 Fax: +44 (0) 1707 278695 / Web: wave.mitsubishielectric.co.uk / Email: automation@meuk.mee.com