Exposures to radiofrequency fields from WiFi in New Zealand schools

EMF Services
Professional EMF measurement and advisory services

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About EMF Services and the author of this report

EMF Services is a division of Monitoring and Advisory Services NZ Ltd (MAASNZ), and provides professional measurement and advisory services related to possible health effects of electromagnetic fields (EMFs), such as the extremely low frequency (ELF) electric and magnetic fields found around any wiring, appliances or infrastructure carrying mains electricity, and the radiofrequency (RF) fields produced by radio transmitters and some industrial equipment.

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1 Introduction and summary

This report presents the results of measurements of exposures to radiofrequency (RF) fields from WiFi in two New Zealand schools, both from the access points and devices themselves. The results are compared and supplemented with information from overseas studies.

All exposures were very low compared with the public exposure limit in New Zealand Standard 2772.1:1999 *Radiofrequency Fields Part 1: - Maximum exposure levels 3 kHz - 300 GHz*. The maximum exposure averaged over six minutes was equivalent to 0.024% of (ie about four thousand times lower than) the reference level[1] specified for the public in that Standard, and generally, in a classroom with a WiFi access point mounted on the wall, time average exposures were less than 0.01% of the limit (ten thousand times lower). In classrooms without an access point, exposures were lower still.

Time average exposures measured 30 cm from a laptop were generally less than 0.001% of the reference level The results indicate that the duty cycle of devices is typically less than 0.005 (ie the devices transmit for a total of less than 18 seconds in every hour).

The results from New Zealand are consistent with data published by the British Health Protection Agency (HPA, now part of Public Health England) and Industry Canada.

Exposures to WiFi signals in New Zealand schools, both from the access points and devices, are very low. On this basis WiFi in schools does not pose a health risk to children or staff.

It should be noted that the measurements in New Zealand classrooms did not include exposures from 5 GHz WiFi. In one of the schools (School A), the company which installed and maintained the network stated that the access point transmit power at 5 GHz is only one tenth of that at 2.4 GHz, and all devices were connecting to access points at 2.4 GHz. Assuming similar transmission patterns, the contribution of 5 GHz WiFi could add around 10% to the exposures reported here for School A. At School B, only 2.4 GHz WiFi was in use in the classroom where the tests were made.

Full details of the measurements and results are included in sections 2 and 4 of this report. Section 3 discusses the New Zealand RF field exposure Standard, and section 5 summarises findings of WiFi measurements in Canada and the UK.

[1] The *reference level* is a limit defined in terms of easily measurable quantities, and is discussed in more detail in Section 3.

2 Measuring equipment and techniques

The planning, execution and reporting of the measurement survey followed the procedures recommended in AS/NZS 2772.2:2011 *Radiofrequency fields Part 2: Principles and methods of measurement and computation – 3 kHz to 300 GHz*.

2.1 Measuring equipment

RF fields were measured with a Narda SRM-3006 Selective Radiation Meter and three-axis electric field probe connected to the meter body through a 1.5 m coaxial cable. Full specifications are presented in Annexe A.

The meter and probe combination measures electric field strength, which is expressed in units of volts per metre (V/m). For ease of comparison with the exposure limits recommended in NZS 2772.1:1999, the meter was set to record data as the equivalent power flux density of a plane wave, and results in this report are presented as a percentage of the power flux density reference level recommended in the NZ RF field exposure Standard.

2.2 Types of measurement

WiFi access points (APs), and the devices connected to them, transmit intermittently. Normally the transmitting power of the AP and device is fixed, and it is either on (transmitting) or off. The duration of each transmission is short (around a few tens or hundreds of millionths of a second). The fraction of time that a transmitter operates during some time period is called the **duty cycle**. For example, if an AP transmits for one hundred microseconds and is then off for nine hundred microseconds the duty cycle is 0.1.

Two types of measurement are reported in this survey:

- **Time average exposures** are the values of the exposure averaged over some time interval, and are of main interest for comparing against exposure limits. The NZ RF field exposure Standard specifies that exposures can be averaged over six minutes, but exposures averaged over one minute are also presented in this report.
- The **maximum instantaneous exposure** is the peak exposure measured at a point, while the WiFi or a device connected to the WiFi is transmitting. The main interest in determining the maximum instantaneous exposure is to help determine the duty cycle.

2.3 Measurement technique

Measurements with the SRM-3006 were made in safety evaluation mode. In this mode, the meter shows the power flux density in each of one or more preset frequency bands (called "services" in the instrument terminology). As the purpose of this survey was to determine exposures from WiFi, service tables were set up which covered either the whole WiFi band, or individual WiFi channels. These tables are summarised in the table in Appendix B.

2.3.1 Measurements in classrooms

For measurements in classrooms, the probe was held on a stand with the head 90 cm above the floor (the approximate height of a seated pupil). The meter was set to average the readings over one minute in automatic isotropic mode, and store the current value of

this quantity, and the maximum instantaneous exposure, every minute for six minutes. The stored readings were later downloaded from the meter, and the exposure averaged over six minutes calculated from the individual one-minute averages.

Measurements in a classroom

2.3.2 Measurements on devices

Measurements of the maximum instantaneous exposure were made on a few devices, from which the time average exposure can also be determined if the duty cycle is known. Time average exposures were measured over periods of an hour for a PC entering data continuously into a Google word processing document, and for a PC in general use (including some broadband speed tests). Together with the maximum instantaneous exposure, these can be used to estimate the duty cycle.

Measurements on devices were made far enough away from the AP that any contribution from the AP itself to the measured exposure was much lower than from the device.

Measurements on devices were made in safety evaluation mode, using a service table corresponding to the WiFi channel being used by the device (determined by looking at the spectrum.) To find the maximum possible exposure, the device was set to upload a large file, and the meter used in manual isotropic mode. Two or three measurements were

made on each measurement axis to ensure that the maximum possible value was read, and the readings from all three measurement axes combined to give the total.

Measurements in front of an ASUS laptop

It should be noted that only a single measurement was made in each setup, opposite the centre of the device display, and that this may not be the highest that might be attained at the measurement distance. It is possible that higher and lower values could be found if the probe were swept across the face of the device at a fixed distance from it. Carrying out a more detailed evaluation like this was beyond the scope of this survey. On the other hand, laptop antennas (of which there may be more than one) are often at the top of the screen, and do not have particularly strong directional characteristics[2] in front of the screen (see, for example, data presented by the UK Health Protection Agency in 20011[3]) so there are not likely to be large differences.

In order to gauge the duty cycle of transmissions from the devices, and hence determine the time average exposure, further measurements were made near some devices in the same manner described in section 2.2.1, but over longer periods of time. These measurements show the time average exposure, and the duty cycle can be estimated by dividing the time average exposure by the maximum instantaneous exposure.

[2] In other words, they do not transmit much more strongly in some directions than others

[3] Peyman et al. Assessment of exposure to electromagnetic fields from wireless computer networks (Wi-Fi) in schools: results of laboratory measurements. Health Physics 100 (6), 594-612 (2011)

3 Exposure Standards

The New Zealand Ministry of Health recommends using NZS 2772.1:1999 *Radiofrequency Fields Part 1: Maximum exposure levels – 3 kHz to 300 GHz* to manage exposure to RF fields. This Standard is based closely on Guidelines published by the International Commission on Non-Ionising Radiation Protection (ICNIRP). ICNIRP is an independent scientific body recognised by the World Health Organisation for its expertise in this area. Their exposure Guidelines, which are based on a careful review of the health effects research, were first published in 1998[4], and reaffirmed in 2009[5] following a review of more recent research in this area[6].

NZS 2772.1 sets limits for exposure to the RF fields produced by all types of transmitters, and covers both public and occupational exposures. Occupational limits should normally be applied only to people who are expected to work on RF sources (eg radio technicians and engineers, riggers, RF welder operators etc), who have received training about potential hazards and precautions which should be taken to avoid them. Their exposures to occupational levels would normally be limited to the working day and over their working lifetime. Occupational exposure limits are set at levels 10 times lower than the threshold at which adverse health effects might occur. Public limits are intended to protect all members of the population, of all ages, who may be exposed 24 hours per day, seven days per week, and incorporate a safety factor of 50.

The Standard sets fundamental limits, called **basic restrictions**, on the amount of RF power absorbed in the body from a radio signal. This is quantified as the **specific absorption rate** (SAR), measured in watts/kg. For the public, the Standard sets a limit of 0.08 W/kg on the average power absorbed over the whole body. The localised SAR in different parts of the body will, of course, vary above and below the average, and the Standard also specifies that in the head and trunk the maximum localised SAR should not exceed 2 W/kg over any 10 grams of tissue.

In practice, SAR is very difficult to measure and not practical for environmental measurements. For that reason, the Standard also specifies secondary limits, called **reference levels** in terms of the more readily measured (or calculated) electric and magnetic field strengths of the radio signal, and the plane wave equivalent power flux density. The reference levels are set so as to ensure that if exposures comply with them, they will also comply with the basic restrictions on SAR. In many situations they can effectively be regarded as the NZS 2772.1 "exposure limits", although this term is not used as such in the Standard.

If exposures exceed the reference levels, this does not necessarily mean that the basic restriction has also been exceeded. However, a more comprehensive analysis is required before compliance can be verified.

For a given strength of radio signal, the SAR depends on the frequency of the signal. For that reason, the reference levels vary with frequency. At the frequencies used by WiFi, the reference level for the public is 1,000 microwatts per square centimetre ($\mu W/cm^2$).

[4] http://www.icnirp.de/documents/emfgdl.pdf
[5] http://www.icnirp.de/documents/StatementEMF.pdf
[6] http://www.icnirp.de/documents/RFReview.pdf

The limits prescribed in the Standard are average values over six minutes. If the signal varies widely over short distances, spatial averaging, at the four corners and centre of a square whose sides are 25 - 30 cm long (depending on the frequency), is also permitted.

As well as compliance with the numerical limits, Clause 10(d) of NZS 2772.1 requires:

> "Minimizing, as appropriate, RF exposure which is unnecessary or incidental to achievement of service objectives or process requirements, provided that this can be readily achieved at modest expense."

An explanatory note to this clause comments:

> "Notwithstanding that ICNIRP considers that the basic restrictions and reference levels in this Standard provide adequate protection, it is recognized that community concerns over RF exposure may be able to be addressed by further minimization of exposure in accordance with the requirements of Clause 10(d).")

Effectively, this means that when installing radio transmitters simple steps should be taken to minimise exposures if this can be achieved at low or no cost, and without compromising the performance of the system. In the context of school WiFi installations, possible options to minimise exposures include:

- If the power of an AP is adjustable, it should be set to the lowest value which still achieves the required coverage
- When positioning APs, place them high up or even in corridors or cloakrooms (if this provides the necessary coverage).

Often, such measures are best taken when a system is initially installed, as making changes later on may not be simple or low cost.

For the devices themselves, exposures can be minimised by using them on a desk or table rather than on the lap (as this increases the distance between the transmitting antenna and the body). WiFi technology by its very nature also acts to minimise exposures from devices as the length of time they transmit must be kept as low as possible in order to allow other devices to share the same WiFi channel.

4 Measurement results

Measurements were made in two schools, referred to as School A and School B. Results are graphed in the following sections (4.1 for school A, 4.2 for school B) and the following quantities are presented in the graphs:

Quantity	Relevance
Exposure averaged over six minutes	This is the most relevant quantity for comparing against the reference level in the NZ exposure Standard.
Maximum instantaneous exposure	The maximum instantaneous exposure measured over the six minute recording interval. (This could be due either to the AP, or to a nearby device.) If devices are mostly inactive, the ratio of the six-minute average exposure to the maximum instantaneous exposure gives an estimate of the AP duty cycle. If measurements are made in front of a device, and the AP is some distance away, the ratio of the six-minute average exposure to the maximum instantaneous exposure gives an estimate of the device duty cycle.

The measurement locations (identified by words, letters and/or numbers) are shown along the bottom of the graphs, and a table below each graph describes the position of each measurement location.

At each measurement location, the green diamond shows the exposure averaged over six minutes (the averaging time specified in the Standard), and the red circle shows the maximum instantaneous exposure.

Hence in the first graph in section 4.1.1, which shows exposures in Room 1 of school A, at the point labelled 2 (2 metres back from the wall of the classroom on which the access point is mounted) the exposure averaged over six minutes was 0.024% of the reference level. The maximum instantaneous exposure at this point was 0.22% of the reference level.

In order to display the wide range of values encountered, exposures are displayed on a logarithmic (compressed) scale.

4.1 School A

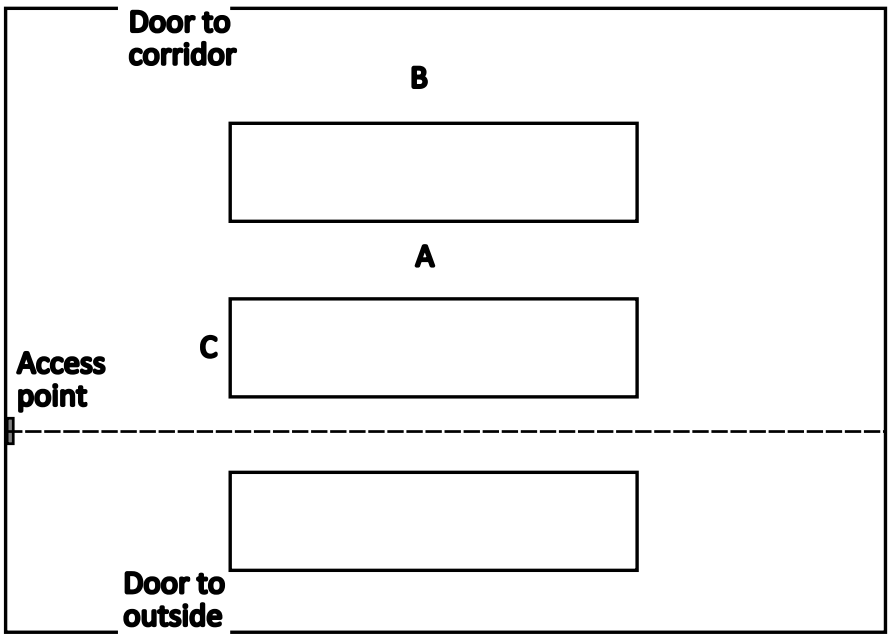
Measurements were made in the following areas:

Area	Description	Measurements made
Room 1*	Classroom with an AP mounted about two metres above floor level at one end of the room	Measurement at one metre intervals from the front to the rear of the classroom, in line with the AP, and towards the sides of the room. Some measurements made with many active devices, some with few or none.
Room 2	Classroom with no AP, about 30 m from the closest AP	Single measurement in one corner of the classroom
Room 3	Classroom with an AP mounted about two metres above floor level at one end of the room	Single measurement about 2.5 m back from the wall on which the AP is mounted
Room 4	Classroom next to Room 1, Room 1 AP at the far end of the classroom from the wall dividing Rooms 1 and 4	Single measurement about 2 m back from the wall dividing Rooms 1 and 4
Reception	At school entrance/reception, about 12 m from closest AP (which is in a separate room)	Single measurement in the centre of the reception area.

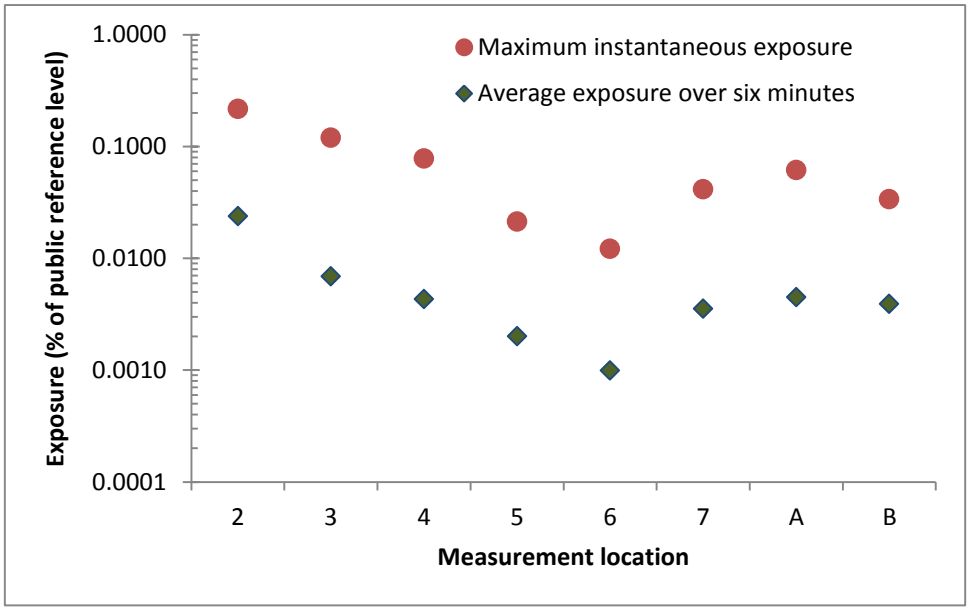
*Note: room numbers do not correspond to the actual classroom numbers used in the school.

4.1.1 Room 1 – general

The sketch plan of the classroom below shows where measurements were made.



Sketch plan of Room 1. Dashed line shows line along which measurements were made as a function of distance. Point labelled C shows where measurements were made near operating laptops.

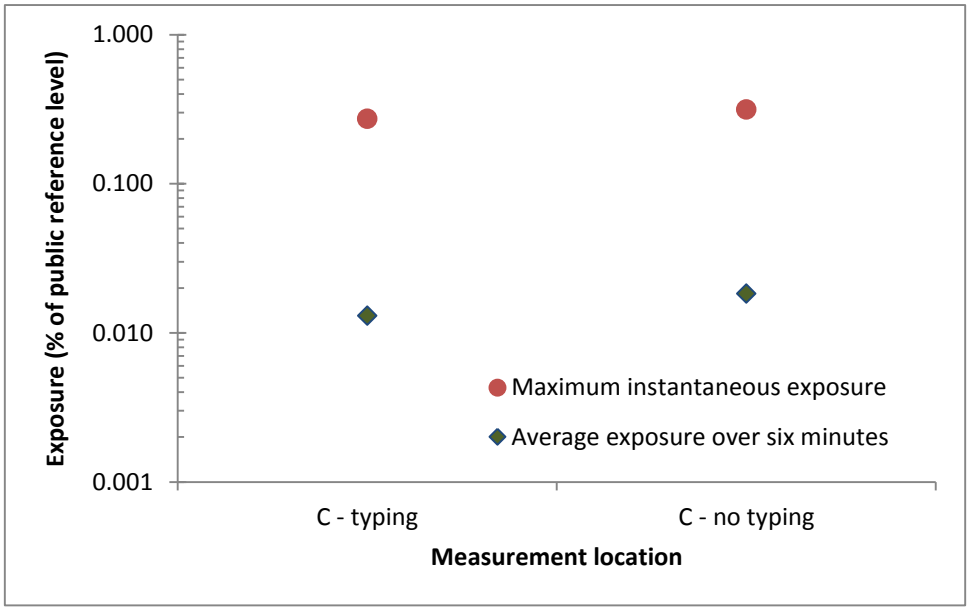


Exposures measured in Room 1

Location	Description
2	2 metres back from the wall on which the AP is mounted – pupils all busy typing
3	3 metres back from the wall on which the AP is mounted – little activity
4	4 metres back from the wall on which the AP is mounted – little activity
5	5 metres back from the wall on which the AP is mounted – little activity
6	6 metres back from the wall on which the AP is mounted – little activity
7	7 metres back from the wall on which the AP is mounted – little activity
A	Half way along classroom – between desks (see sketch plan) – little activity
B	Half way along classroom – between desks (see sketch plan) – little activity

4.1.2 Room 1 – near active laptops

The measurement probe was placed in the position marked C in the sketch plan, about as far away from two active laptops as the bodies of the pupils using them. A measurement was made while the children were busy typing, and also while the laptops were still there but the pupils had gone for lunch.

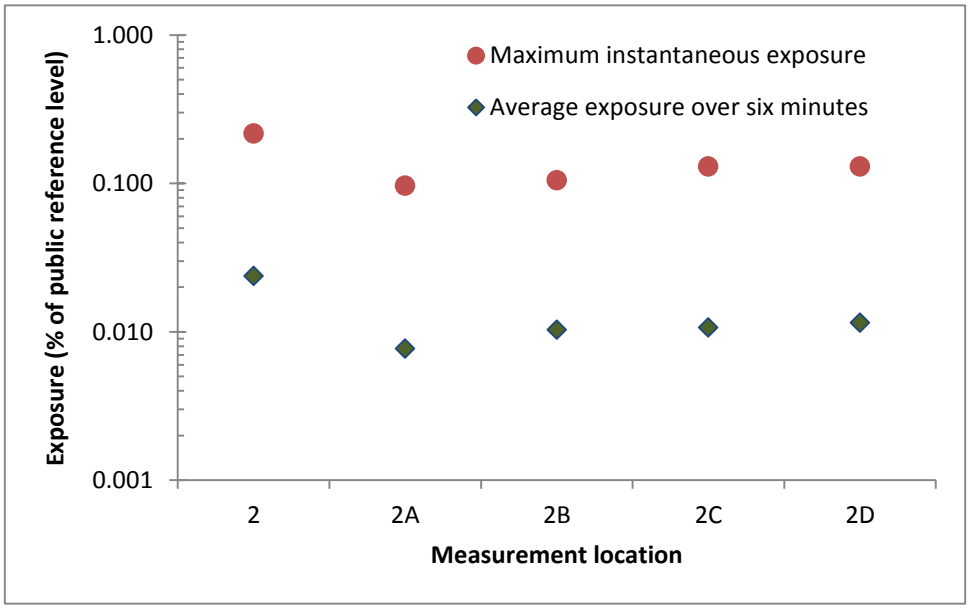


Exposures by desk with laptops in Room 1

Location	Description
C - typing	By desk with laptops – pupils typing
C – no typing	By desk with laptops – pupils not typing

4.1.3 Repeated measurements at the same point

Over the course of the afternoon when the measurements were made, several measurements were made in Room 1 at the point 2 m from the wall on which the access point is mounted. The results are plotted below.

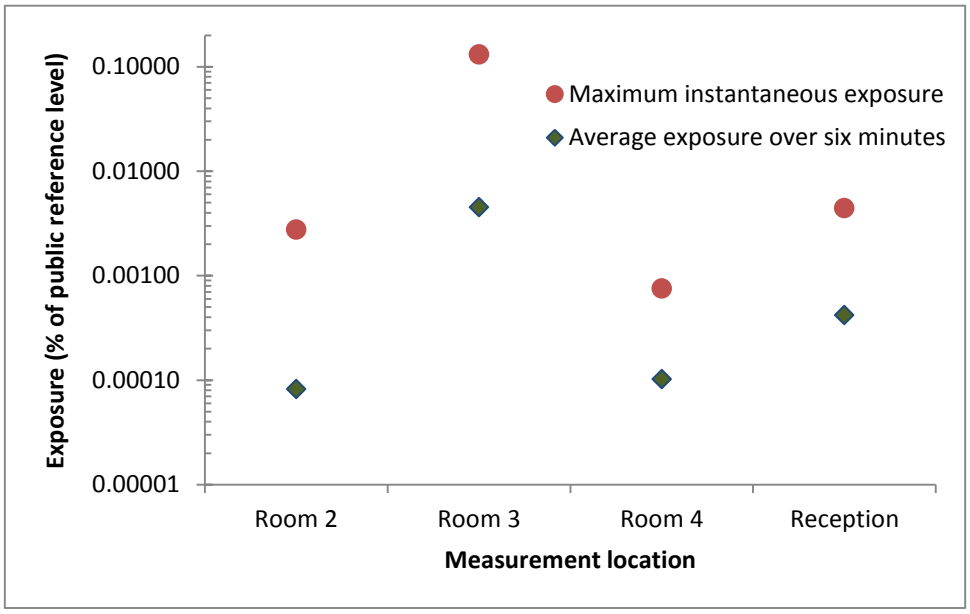


Exposures in Room 1 measured 2 m from the wall on which the access point is mounted

Location	Description
2	2 metres back from the wall on which the AP is mounted – pupils all busy typing (same data as in section 4.1.1)
2A	Same position – no typing
2B	Same position – no typing
2C	Same position – no typing
2D	Same position – large file being downloaded from AP during the measurement

4.1.4 Other areas

Measurements taken in other areas are plotted below.



Exposures in Rooms 2, 3 and 4, and at the reception

Location	Description
Room 2	Near corner of classroom, about 30 m from nearest AP
Room 3	2.5 m away from wall on which AP mounted
Room 4	About 10 m from closest AP, through a dividing wall
Reception	Centre of school reception area

4.2 School B

Measurements were made in a classroom with an AP mounted on an end wall, about 2 m above the ground.

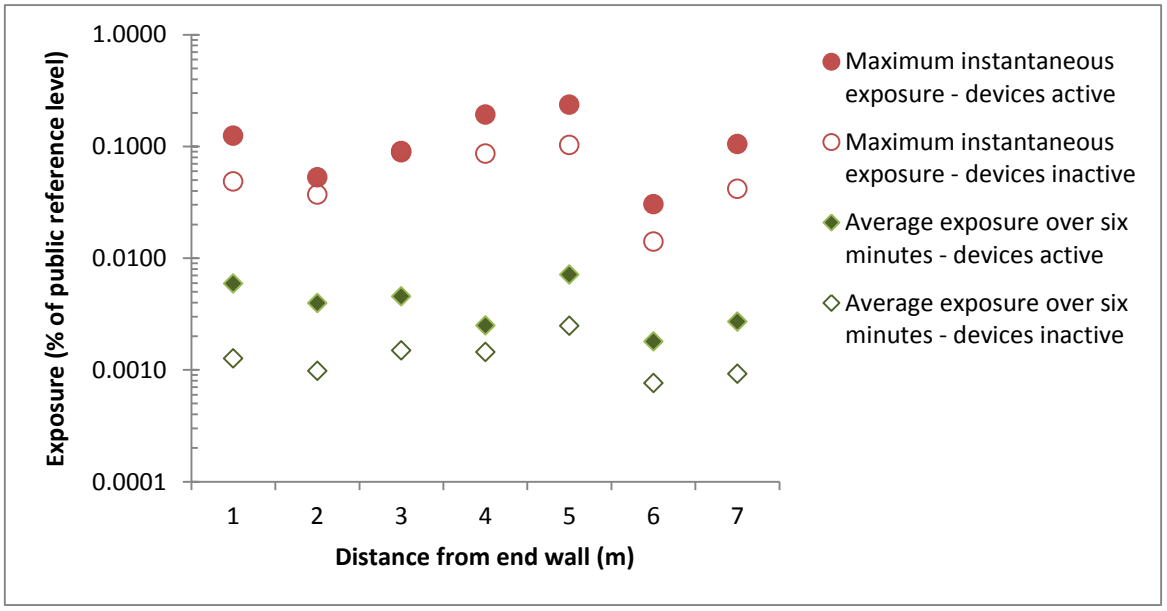
4.2.1 Exposures as a function of distance from the end wall

Two sets of measurements were made with the probe positioned at one metre intervals from the front to the rear of the classroom.

In the first set of measurements, ten devices (five HP mini laptops and five iPads) were active, connected to a broadband speed test site. Five devices were set to carry out a 12 Mbyte upload test (which starts off by downloading 12 Mbytes of random data from a remote server), and as the probe was moved down the classroom these were placed on the five desks nearest to the probe. (The distance from the measurement probe to the closest device varied from about 35 – 80 cm.) The other five devices were set to carry out a 12 Mbyte download test. The upload/download tests were repeated until each exposure measurement was complete.

In the second set of measurements, all devices were kept at least 3 m away from the probe and left inactive (in sleep mode).

Results are plotted in the graph below. Solid green diamonds show the six minute average exposure with the devices active, and open green diamonds show the six minute average exposure with the devices inactive. Solid and open red circles show the maximum instantaneous exposures for the two test conditions.



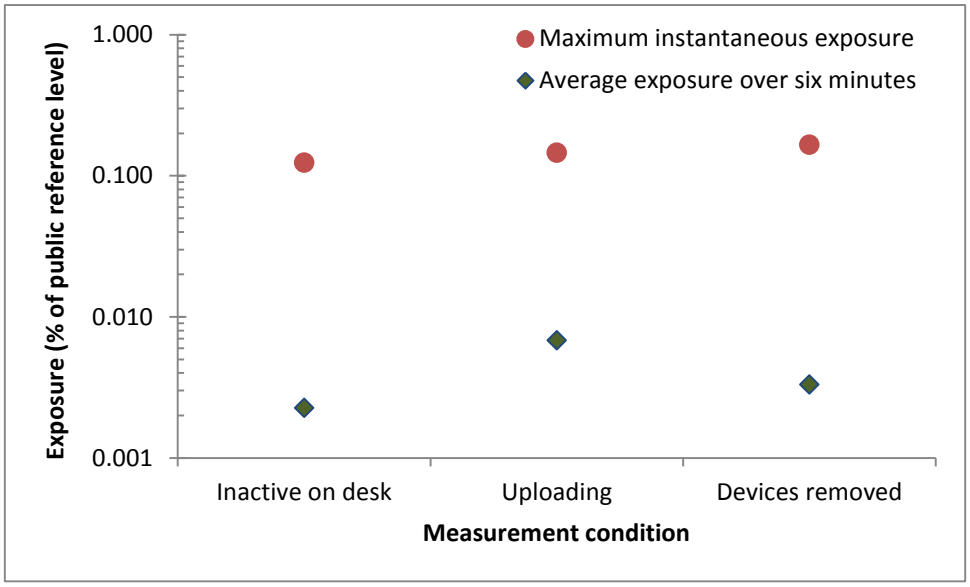
Exposures in School B classroom, as a function of distance from the end wall with the AP

4.2.2 Exposures near active laptops

Six devices were placed on a desk approximately five metres back from the end wall, and the measurement probe positioned about 30 cm away from the screen of the closest laptop (as shown on the photo). Exposure measurements were made:

- With the devices on the desk but inactive
- With all devices repeatedly carrying out a 12 Mbyte upload speed test
- With all devices removed and placed, inactive, at least three metres away.

Results are plotted below.



Exposures by desks with six devices

4.2.3 Exposures in an adjacent classroom

In an adjacent classroom, separated from the classroom with the AP by a cloakroom, the six minute average and instantaneous maximum exposures one metre from the end wall closest to the AP (and about 13 metres away from it) were 0.000054% and 0.0014% respectively of the reference level.

4.3 Measurements near laptops and other devices

This section presents the results of measurements of exposures from laptops and other devices connecting to WiFi.

Section 4.3.1 shows the maximum instantaneous exposures measured near individual devices, and section 4.3.2 shows the time averaged exposures measured while the devices were in use.

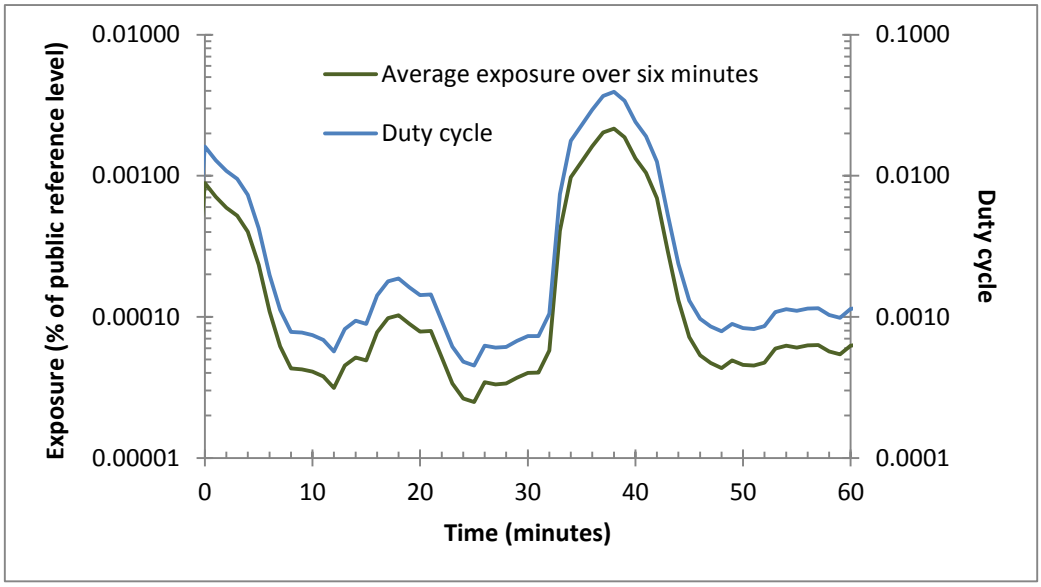
4.3.1 Maximum instantaneous exposures

The maximum instantaneous exposure measured near different laptops and other devices is shown in the table below.

Device	Measurement position	Maximum instantaneous exposure (% of limit)
HP laptop	30 cm from centre of screen	0.05 – 0.08
MacBook	Approx. 40 cm from centre of screen	0.19
Asus laptop	30 cm from centre of screen	0.052
iPad	30 cm above centre of screen	0.16
iPad	25 cm from edge where antenna situated	0.16
HP Mini	30 cm from centre of screen	0.47

4.3.2 Exposures from devices in use

The plot below shows exposures measured 30 cm from the screen of an HP laptop (device at the top of the table in section 4.3.1 above) during normal use.

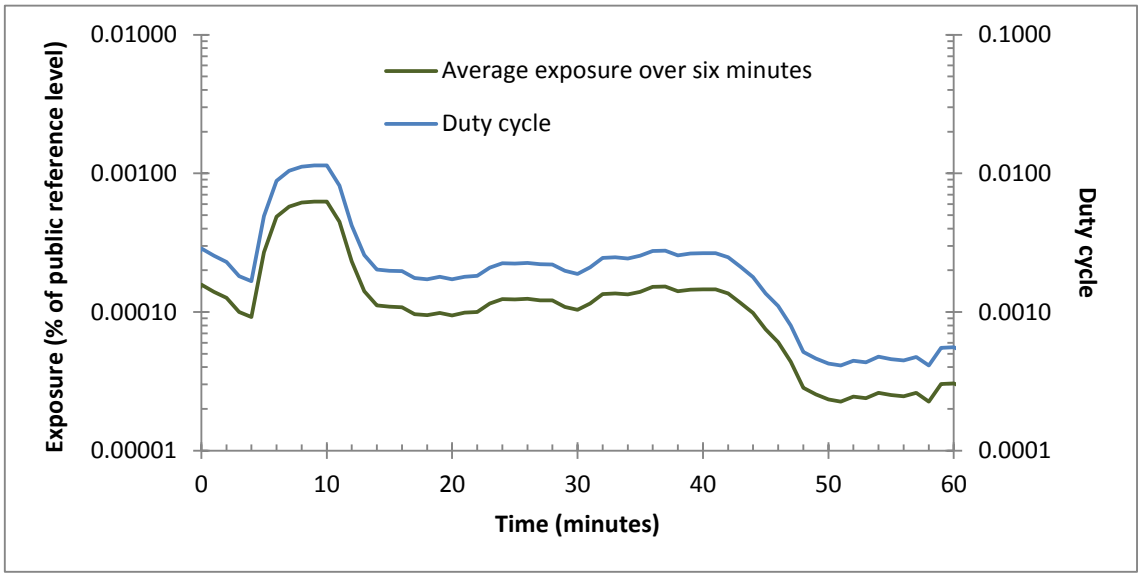


Exposures from HP laptop in normal use

The green curve shows the exposure during use, averaged over one minute, and the value of this curve should be read off against the scale on the left. The blue curve shows the approximate duty cycle of the WiFi transmitter in the laptop (right hand scale).

For a few minutes after starting to record the data, and about 35 minutes into the test, a 25 MByte upload speed tests was run to get the WiFi uplink from the laptop as busy as possible. The graph shows that during this time the laptop WiFi transmitter had a duty cycle of about 0.04 (ie the transmitter was busy for about 4% of the time). The rest of the time, the duty cycle was about 0.001.

The plot below shows exposures measured from an HP laptop while editing a Google Docs word processing document. A key was held down continuously for the first 45 minutes of the data recording, so as to simulate the fastest possible typing speed. After that, the word processing document was left open, but not edited.



Exposures from HP laptop while editing Google word processing document as fast as possible

The traces have the same meanings as in the previous example. Most of the time the exposure was between 0.0001 and 0.0002% of the public reference level, and the duty cycle around 0.003. The reason for the increase in exposure and duty cycle after about 8 minutes, and whether this was related to the Google Docs or some other process running in the background is unknown. (Another test on the same laptop did not show such an increase.) During this time, the exposure increased to about 0.0006% of the reference level, and the duty cycle to 0.01. The exposure with the Word processing document open but not being edited was 0.00003% of the reference level.

5 Overseas data

There are two sets of overseas data which provide comparative and/or complementary information.

5.1 Canadian measurements in a "simulated classroom setting"

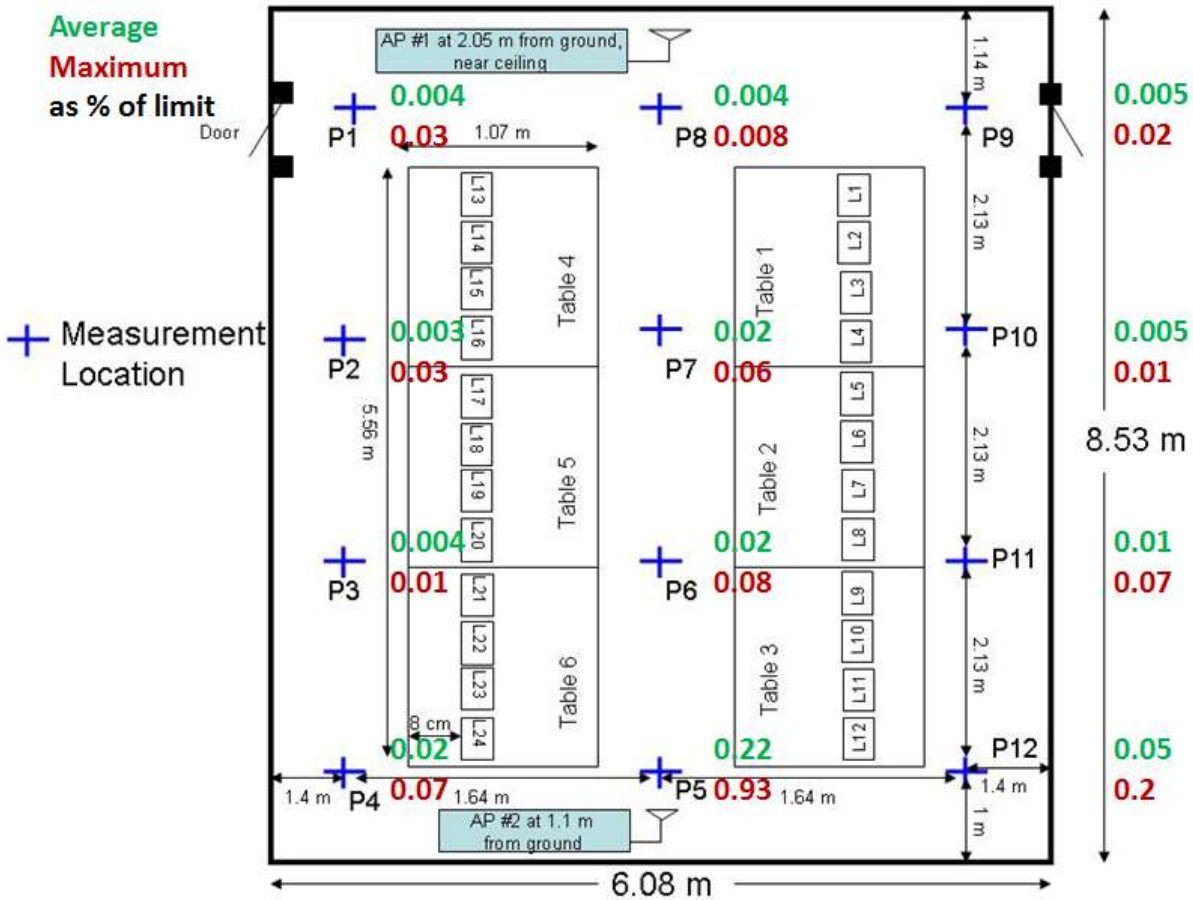
In 2012 Industry Canada published the results of measurements of WiFi exposures in what they described as a "simulated classroom setting"[7]. A meeting room as set up with a 5 GHz WiFi AP at one end and a 2.45 GHz AP at the other, and 24 laptops uploading and downloading data.

The 5 GHz AP was mounted by the ceiling and put into a test mode to transmit continuously at a power of 0.25 W. The AP antenna had a gain of 5.6. The 2.45 GHz AP was placed about 1.1 m above the floor. This AP was in normal operating mode, with a power of 0.25 W when transmitting. The gain of its antenna was 9.

A photograph of the setup, looking towards the 5 GHz AP, is shown below.

Measurements were made at 12 positions around the room. Maximum and time averaged exposures at 2.4 GHz (which would include the contributions from the AP and the laptops) AP when all the laptops were downloading a large file are shown in the sketch plan below. For these measurements, the probe was 1.25 m above the floor.

[7] Available at: http://www.ic.gc.ca/eic/site/smt-gst.nsf/eng/sf10383.html



Exposures in a simulated classroom setting with all laptops downloading a large file from the 2.45 GHz AP (AP #2, shown at the bottom of the sketch plan). P1 – P12 show the measurement locations. P5 is 43 cm from the 2.45 GHz AP. Figures in green and red show the time average and maximum exposures respectively, as a % of the public reference level.

In another test, the eight laptops on tables 1 and 4 were set to upload a large file while the other 16 laptops downloaded, and the measurement probe was placed 50 cm on the P8 side of P7 (about 1.1 m from the laptop lids). The average and maximum exposures were 0.005% and 0.05% respectively of the public reference level.

Results of other measurements carried out in this test setup are available in the original report.

5.2 UK measurements

The UK Health Protection Agency (HPA, now part of Public Health England) carried out an extensive series of tests to determine the transmitting power of APs and laptops used in UK schools, duty cycles in schools and SAR from devices. A summary of the findings is in Appendix A of an HPA report *Health effects from radiofrequency electromagnetic fields*[8], which also contains references to publications with more detailed results.

Amongst the findings were the following:

- The maximum exposure one metre from an access point, if it transmits continuously, is 0.18% (ie about 500 times lower than) the reference level in the Standard.

[8] Available at: www.hpa.org.uk/webw/HPAweb&HPAwebStandard/HPAweb_C/1317133826368

- The duty cycle of access points in a sample of classrooms varied between 0.01 and 0.117 (ie they transmitted for between 36 seconds and about 7 minutes per hour)
- Duty cycles of devices being used in classrooms varied between 0.0002 – 0.0091 with a mean of 0.0008 (ie they transmitted for a total of between 0.7 and 33 seconds per hour, with a mean of 3 seconds).
- The transmit power of devices (all laptops) at 2.45 GHz varied between 5 and 17 milliwatts, with a mean of 11 mW.
- The transmit power of APs at 2.45 GHz varied between 3 and 28 milliwatts, with a mean of 11 mW
- Taking into account the measured duty factors, the maximum localised SAR in the torso of a 10-year old child attributable to devices would be 80 μW/kg (0.004% of the limit on localised SAR)

6 Discussion

6.1 Exposures in classrooms

The measurements in New Zealand classrooms showed the following features:

- Exposures are all well below the limits recommended for the public. The maximum exposure averaged over six minutes was equivalent to 0.024% of (ie about four thousand times lower than) the public reference level[9]. Generally, exposures were less than 0.01% of (ten thousand times lower than) the public reference level.
- In one of the classrooms tested, exposures varied quite markedly from the front to the back (from 0.024% to 0.0010% of the reference level), while in the other there was a lot less variation.
- Exposures in classrooms with no access point were much lower. This can be explained by the decrease in the WiFi signal strength with distance from the AP, and attenuation by the classroom walls.

It should be borne in mind that these were field measurements, and not all conditions which might affect exposures could be controlled as they might be in a laboratory setting. Hence some variation in results should be expected if the same exercise were repeated because, for example, the exposure can vary over distances of a few centimetres, and it is very difficult to reposition a measurement probe with centimetre accuracy. In addition, radio waves at these frequencies can be reflected off many surfaces, including the body, so variations at a point will also occur as people move around the classroom, especially near the measurement probe.

6.2 Exposures from devices

Measurements on a device in normal use, and while editing an online word processing (Google Docs) document, showed that it had very low duty cycles, and that time average exposures were much lower than from APs. Maximum time average exposures near devices can be estimated by multiplying the maximum instantaneous exposure by one of the duty cycles shown in section 4.3.2, or from the UK data discussed in section 5.2. The combined effect of exposures from the AP and from a device (or several nearby devices) can be estimated by adding up the exposure from the AP and the exposure from the device(s). (Note that the exposure from a device decrease in proportion to the inverse square of the distance, so exposures 1 m from a device are a quarter of the exposure 50 cm from it.)

It should be noted that these measurements were made several tens of centimetres away from a device. If a device is used in contact with the body (for example an iPad on the lap), the exposure can be estimated by obtaining the SAR of the device from equipment manuals, and multiplying by the expected duty cycle of the device. The exposure as a percentage of the limit in NZS 2772.1 can be found by dividing this value by 2 and converting to a percentage.

6.3 Particular features of the measurements

- In School A, there was little change in the six minute average exposures between when the laptops were in use and not being used (section 4.1.2). In School B, the data in

[9] Although not presented in section 4, the maximum exposure averaged over any one minute interval was 0.031% of the reference level.

sections 4.2.1 and 4.2.2 shows that the six minute average exposures were generally around 3 times higher when the devices were active, compared with when they were inactive or removed. A possible explanation for this is that in School A, the nature of the laptop activity (editing a Google Docs document) made little difference to the average exposure, whereas the more intense data transfers during a speed test do result in a noticeable change. This explanation is supported by the low duty cycle noted in section 4.3.2 while editing a Google Docs document.

- The results presented in section 4.2.1 for the School B classroom show that at most distances the maximum instantaneous exposure was higher with the devices active than inactive. Possible explanations for this are:
    - The instantaneous exposure measured with the devices active reflects a genuinely higher exposure, due to the proximity of the active devices, and shows the exposure due to the nearest device.
    - When the devices were inactive the maximum instantaneous exposure is underestimated due to the sampling nature of the measurements.
    - A combination of both explanations.

  More detailed data would be needed to better understand this. However, the possibility that the higher instantaneous exposures are due to exposures from the laptops adding to the AP exposures can almost certainly be discounted, because WiFi protocols are designed to minimise the possibility that the AP and a device, or two devices, would both transmit at the same time.

6.4 Exposures in terms of SAR

As discussed in Section 3, SAR is very difficult to measure, and in most situations the strength of the radio signal is measured instead, and compared to "secondary" reference levels (reference levels) derived from the fundamental limits on SAR. SAR measurements are mostly used when assessing exposures from devices which are held very close to the body (within a few cm), such as mobile phones.

However, data from a recent publication[10] allow SAR to be estimated from plane wave equivalent power flux density measurements such as those made in this survey. This shows that the maximum six-minute average exposure of 0.024% of the limit is equivalent to a maximum localised SAR value of 0.00048 W/kg, which is about four thousand times lower than the limit of 2 W/kg for localised SAR.

6.5 Effect of 5 GHz WiFi

The measurement equipment used in this survey does not measure WiFi signals in the 5 GHz frequency band. In School B, a PC-based WiFi detection program indicated that the AP in the classroom was not operating at 5 GHz. While the APs in School A operated at both 2.4 and 5 GHz, staff from the company which maintains the network said that all devices were connecting at 2.4 GHz, and the transmitting power of the AP at 5 GHz was one tenth of that at 2.4 GHz.

Therefore, assuming that the propagation patterns for the 5 GHz WiFi are similar to those at 2.4 GHz, WiFi from the access points at 5 GHz might add about 10% to the exposure values recorded at School A.

[10] Bakker et al. Assessment of induced SAR in children exposed to electromagnetic plane waves between 10 MHz and 5.6 GHz. Phys Med Biol 55 (2010), 3115 – 3130.

Annexe A Measuring equipment specifications and uncertainty

A1 Specifications

Manufacturer	Narda Safety Test Solutions GmbH, Pfullingen, Germany
Meter	SRM-3006 s/n H-0010, firmware v 1.3.1
Probe	3-axis electric field probe 3501/03 s/n K-0543
Cable	1.5 m 3602/01, s/n AA-0565
Measurement range	Lower detection threshold: dependent on measurement parameters (see Appendix B). Upper limit 200 V/m (10,600 $\mu W/cm^2$)
Frequency range	27 MHz – 3 GHz
Calibration	By the manufacturer, March 2012
Recommended calibration interval	2 years

Full specifications are available at:
www.narda-sts.de/fileadmin/user_upload/literature/high_frequency/DS_SRM3006_EN.pdf

A2 Measurement uncertainty

A2.1 Expanded measurement uncertainty of SRM-3006 and probe

Data source: equipment specifications from manufacturer.

Frequency range	**Expanded uncertainty**
27 – 85 MHz	+3.2/-4.8 dB
85 – 900 MHz	+2.5/-3.6 dB
900 – 1400 MHz	+2.5/-2.4 dB
1400 – 1600 MHz	+2.6/-3.8 dB
1600 – 1800 MHz	+2.2/-3.0 dB
1800 – 2200 MHz	+2.4/-3.3 dB
2200 – 2700 MHz	+2.7/-3.8 dB
2700 – 3000 MHz	+3.3/-5.3 dB

This includes all uncertainties associated with the meter, calibration, probe isotropy and connection mismatches, with a coverage factor of 2.

A2.2 Expanded measurement uncertainty for this survey

Parameter	Uncertainty data source	Standard uncertainty *u (dB)*
Meter + probe over whole frequency range of interest	Data sheet (as above)	+1.6/-2.4
Position of probe in high field gradients	NZS 2772.2 recommends assuming a standard uncertainty of 0.36 dB	0.36
Sampling uncertainty	The SRM measures on a sampling basis. Simple simulation of variations in time-averaged exposures shows that there would be a standard deviation of 5% in six minute averages.	0.21
RF propagation/ environmental clutter	Assume triangular distribution, 1.5 dB semi-span	0.61
	Combined standard uncertainty	+1.76/-2.51
	Coverage factor	2
	Expanded uncertainty	**+3.5/-5.0**

No allowance has been made for the following potential sources of uncertainty:

Potential source	Comment
Signal reflection off operator	Reflections can produce increases and decreases in measured PFD over distances of 100 – 250 mm. Operator stood in positions so as to minimise potential magnitude of reflections, and the probe was moved around slowly in the area of interest to try and find the region with the highest reading.
Signal reflections off movable objects	Some allowance made for the effects of "environmental clutter (eg people moving around, moving furniture) following example in NZS 2772.2.

No allowance has been made for the possible overestimation of time average exposures where the signal is very low.

Annexe B SRM-3006 preset frequency band, and settings

B1 Measurements in classrooms

Service table (preset frequency band)	**Explanation**	**Lower frequency** (MHz)	**Upper frequency** (MHz)	**Detection threshold*** (nW/cm^2)
WiFi	All 2.4 GHz WiFi band	2400	2483	0.71

* For a measurement range of 4 $\mu W/cm^2$

Settings

Measurement range:	Mostly 4 $\mu W/cm^2$.
Result type:	One minute average, six minute average taken as the average of six consecutive values recorded every minute
Resolution bandwidth:	500 kHz

B2 Measurements on devices

Service table (preset frequency band)	**Explanation**	**Lower frequency** (MHz)	**Upper frequency** (MHz)	**Detection threshold*** (nW/cm^2)
WiFi Ch 11 (or other channel as appropriate)†	WiFi channel 11	2451	2473	0.047

* For a measurement range of 4 $\mu W/cm^2$

† Other channels and frequency ranges used as appropriate

Settings

Measurement range:	Mostly 1 $\mu W/cm^2$.
Result type:	One minute average, six minute average taken as the average of six consecutive values recorded every minute
Resolution bandwidth:	500 kHz