



Effectiveness of laundering processes used in domestic (home) settings

October 2013

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We would like to thank the following people for reviewing this report and for their valuable suggestions and contributions. Please note that the opinions and interpretations expressed in this review do not necessarily represent their views:

Prof. Dr Dirk Bockmühl, Hochschule Rhein-Waal University, Germany; Dr Montes Bosch, Leitatz Technological Centre, Germany; Dr Jürgen Gebel, Executive Manager of the Disinfectant Commission in the VAH, Institute for Hygiene and Public Health, University of Bonn, Germany; Professor Susanne Knochel, University of Copenhagen, Denmark; Prof. Dr H-P Werner, HygCen, Austria; Prof. Dr PMJ Terpstra, University of Wageningen Netherlands; Prof. L. Vossebein, Hochschule Niederrhein University of Applied Sciences, Mönchengladbach, Germany; Dr Jenny Wilson, Institute for Practice, Interdisciplinary Research and Enterprise, University of West London, UK.

Acknowledgement of sponsorship: IFH would like to thank the International Association for Soaps, Detergents and Maintenance Products (AISE) for supporting the preparation of this report.

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<http://www.ifh-homehygiene.org/best-practice-review/hygiene-procedures-home-and-their-effectiveness-review-scientific-evidence-base>

Details for citation of the paper: Bloomfield SF, Exner M, Signorelli C, Scott EA, Effectiveness of laundering processes used in domestic (home) settings (2013) International Scientific Forum on Home Hygiene. <http://www.ifh-homehygiene.org/review/effectiveness-laundering-processes-used-domestic-home-settings-2013>

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Summary

- The aim of this review is to summarise and evaluate the scientific evidence on the effectiveness of domestic machine laundering in reducing the risks of transmission of infections and of antibiotic resistant strains amongst family members.
- In order to save energy, increasingly over the past few years, home laundering has been carried out at lower temperatures (30-40°C). A key aim of this review is to evaluate whether and to what extent the effectiveness of domestic laundering may be compromised by laundering at temperatures of 30-40°C, as opposed to 60°C. Throughout this report the term “effectiveness” is used to describe this process.
- The literature was searched to identify peer-reviewed published data on the effectiveness of machine laundering processes. The 29 publications which were identified were evaluated and data extracted on the effectiveness of laundering (expressed as log reduction in the microbial levels on contaminated fabrics) under different conditions. In particular the impact of temperature, detachment and rinsing, and detergent formulation on hygiene effectiveness was recorded for each study. Other determinant factors which were evaluated were the impact of soiling, details of the machine wash process (wash time, volumes of wash water, number of rinse cycles etc.) and the impact of drying and ironing.
- From studies where the impact of temperature, detachment and rinsing, and detergent formulation was evaluated systematically, it was concluded that each of these factors significantly contribute to the effectiveness of laundering. The data shows that decrease in temperature can significantly increase numbers of survivors on contaminated fabrics, and the transfer of microbes to other items included in the wash. The inclusion of detergent in the wash is associated with a significant decrease in numbers of microbes found on laundered fabrics and decreased transfer of contamination within the wash load. This reduction can be further enhanced where activated oxygen bleach (AOB) is included in the detergent formulation.
- A major difficulty of interpreting the data in this report is the extent of the variability in the results obtained from different studies under any given set of condition e.g. laundering at 30°C. The most likely source is the lack of standardisation of test conditions in the published data. Particularly, the data suggests that the specified temperatures are not achieved in many current models of domestic washing machines. Because of the variability in methodology between studies, and gaps in methodological information, in many cases, interpretations about the extent of the impact of changes in temperature, detergent formulation, washing conditions must be regarded as relative indications rather than absolute values.
- In 2011 IFH carried out a detailed review of the potential infectious disease risks associated with clothing, household linens etc. The overall conclusion from the 2011 and this 2013 IFH report is that that clothing, household linens etc. are risk factors for transmission of potentially harmful microbes in the family home, although they may be less than those associated with hands or other frequent hand and body contact surfaces. It is concluded that these risks need to be properly investigated, assessed and suitably managed as part of a multibarrier approach to home hygiene. Tackling antibiotic resistance is a global priority, and since the publication of the 2011 IFH laundry report, there has been increasing awareness that infection prevention and control measure in hospital and hygiene practices in the home and community are a central part of reducing spread of drug-resistant organisms such as meticillin resistant *S.aureus* (MRSA) and faecal organisms carrying multidrug resistance determinants in the community as well as in hospitals. As persistent nasal, skin or bowel carriage of these strains in the healthy population spreads “silently” in the community, the risks of infections from drug resistant strains in both hospitals and the community increases. The risks are such that home laundering should be able to not only reduce the risk of transmission of infectious illnesses amongst family members, but also reduce the

“silent” spread of antibiotic resistant strains such as MRSA or multidrug resistant gram negative species which may be carried (e.g on the skin or within the normal bowel flora) amongst healthy family members. Even with modern approaches, it is difficult to quantify the risks associated with domestic laundry. Because of this, and the lack of precision about LR values obtained, it is difficult to determine with any degree of confidence the likely effectiveness of laundering under any given conditions and thus give informed advice to consumers (and those involved with developing washing machines, laundry detergents etc.) on appropriate and optimum conditions for laundering of clothing to manage risks of spread of infection and/or colonisation with resistant strains.

- IFH recognises the need to move to low temperature (30°C) laundering in order to conserve energy usage, but this review together with the 2011 IFH report suggest that it is also advisable, in public health terms, that steps are taken to ensure that, this is achieved without compromising hygiene effectiveness. This report suggests that there are good possibilities to achieve this through one or a combination of approaches which include the use of AOB-containing detergents, optimizing detachment through enhance detergency, optimizing dilution through rinsing, or the use of “detergent”/microbicidal rinse products etc., It could also include targeted changes in drying and ironing practices.
- Further work is required to gain a better picture of the impact of laundering at reduced temperatures, and the ways in which this could be done without compromising laundry hygiene.

In response to current needs, IFH has developed guidance on home laundering of clothing and household linens. This is set out in Appendix 1. The proposed guidance is the consensus view of the IFH, based on the findings of this report, and the feedback of, and opinions expressed by, the other members of the panel of experts who examined the report. However, the inconsistency in the published data couple with the data showing that in reality many modern washing machines do not reach the temperature specified on the machine controls makes it extremely difficult to propose guidelines for home laundering with confidence, without first generating better data.



1. INTRODUCTION

In 2011 IFH carried out a review of the infectious disease risks associated with clothing, household linens etc.¹ From this review, it was concluded:

*“Overall the weight of evidence indicates that clothing and household linens are a risk factor for transmission of infection in home and everyday life settings during normal daily activities. Unfortunately, the data is not sufficient to make any quantitative assessment in terms of the impact of promoting effective laundry practices on disease rates. Although it seems likely that the risk is significant, the ‘daily life risks’ are probably somewhat less than those associated with hands, hand contact and food contact surfaces and cleaning cloths which are seen as the key routes of infection transmission. Importantly, the data show that in some situations i.e. where someone in the home is infected, or there is someone with reduced immunity to infection, the infection risks can substantially increase. In particular the data suggests that clothing and household linens are risk factors for spread of *S. aureus* (both antibiotic sensitive and resistant MRSA strains). Risk associated with the increasingly common practice by healthcare workers of laundering their uniforms in their own homes needs to also be addressed*

It was concluded that, although laundry processes should be able to deliver clean fabrics with minimum, use of water, power and chemicals, it is equally important to ensure that laundered clothing does not represent a risk in relation to the transfer of potentially harmful microorganisms.”

In 2002 IFH prepared a review of the effectiveness of hygiene procedures including laundry procedures, as used in the home.² This report sets out to re-evaluate the hygiene effectiveness of laundering processes with specific reference to data published since 2002. The effectiveness of laundering is also reviewed by Kagan *et al.* 2002³, Wilson *et al.* 2007⁴ and Bockmuhl 2011^{5,6}.

2. AIMS AND OBJECTIVES OF THIS REPORT

Aim of this report

The aim of this review is to summarise and evaluate the scientific evidence on the effectiveness of domestic machine laundering in reducing risks of transmission of infections and of antibiotic resistant strains amongst family members. In order to save energy, increasingly over the past few years, home laundering has been carried out at lower temperatures (30-40°C). A key aim of this review is to evaluate whether and to what extent the effectiveness of domestic laundry procedures in reducing microbial contamination on clothing etc. may be compromised by laundering at temperatures of 30-40°C, as opposed to 60°C. Throughout this report the term “effectiveness” is used to describe the impact of laundering in reducing microbial contamination levels on clothing.

The objectives of this project are:

- To conduct a search to identify peer-reviewed published literature on the effectiveness of machine laundering processes and product types
- To prepare a summary of the relevant data from individual publications
- To interpret the data in order to see what conclusions can be drawn about the separate and combined effects of wash and rinse cycles, powder/liquid formulation and temperature in reducing contamination on laundry, and the impact of reductions in the use heat on the effectiveness of machine laundering processes

- To assess what conclusions can reasonably be drawn about the effectiveness of laundering in reducing infection risks, and what further research is needed to reach clearer conclusions
- To formulate guidance on conditions for laundering of clothing etc. in the domestic setting.

3. DATA SOURCES AND HANDLING OF DATA

This review is based on the database of scientific literature accumulated by IFH over the past 15 years. The review also contains data identified from Google Scholar and PubMed database searches using combinations of search terms. Publications were also searched for references to other relevant published data. Publications were analysed and relevant data on the effectiveness of laundering extracted. In order to facilitate interpretation of data, and compare data from different studies, wherever possible the data has been converted into log viable counts of bacteria, viruses etc. and effectiveness expressed in terms of log reductions in counts. Since key parameters such as agitation and rinsing, cannot be simulated by *in vitro* suspension tests the report focuses on studies where contaminated fabrics were subjected to machine wash cycles.

4. FACTORS WHICH DETERMINE THE HYGIENE EFFECTIVENESS OF LAUNDERING

There are three main mechanisms which determine the extent to which microbial contamination of fabrics is reduced during laundering:

Physical removal.

During the main cycle of a household machine washing process soil and the micro-organisms are detached from the fabric and suspended into the wash water. A substantial proportion of these micro-organisms is then removed during the rinse and spin cycles. This mechanism is often referred to as dilution.

Thermal inactivation.

In addition to physical removal, micro-organisms can be killed by heat. In general a higher temperature speeds up thermal inactivation.

Chemical inactivation.

During laundering, chemical inactivation can be achieved using various detergent bleach components. The most commonly used chemicals are tetraacetylenediamine/persalt combinations, now primarily percarbonate, though historically perborate, and sometimes dichloro-isocyanurate. In this report these are referred to as “activated oxygen bleach” (AOB). Adding hypochlorite bleach in the washing process also achieves inactivation.

It is assumed that there is a synergistic effect between detergency, heat and chemical inactivation. A number of other components can also contribute including:

- Where laundry is dried, added microbicidal effect can be achieved particularly from exposure to sunlight where fabrics are dried outdoors
- Drying of clothes in a tumble drier can further reduce microbial load
- Where clothes and linens are ironed, particularly where they are ironed damp, heat and steam penetrating the fabric causes reductions of microbial load
- Microbial contamination will be further reduced if clothes are stored dry.



5. EFFECTIVENESS OF DETACHMENT AND DILUTION, TEMPERATURE, DETERGENT FORMULATION AND OTHER FACTORS IN REDUCING LEVELS OF MICROBIAL CONTAMINATION DURING HOME LAUNDERING

Over the years a range of studies have assessed the effectiveness of heat, detergents and other chemicals, detachment and dilution etc. in reducing the microbial contamination on fabrics. The relevant data from each study has been extracted and summarised in the Appendix. In this section, this data is used to assess the separate effects of detachment and dilution (rinsing), temperature and laundry product formulation on effectiveness. In many cases, however, it is not possible to distinguish the independent effects of individual variables with any real confidence, and sometimes these are obscured because the study conditions provide no real performance differentiation.

5.1 THE EFFECT OF DETACHMENT AND DILUTION DURING LAUNDERING

Wash and rinse cycles contribute to reducing microbial contamination during laundering. A number of the reported studies attempt to assess the independent impact of dilution during wash and rinse cycles. It is difficult to compare results from these studies since many of the factors which determine the impact of dilution depends such as extent of agitation during the wash process, number of rinse cycles and volume of water in each wash or rinse relative to weight of fabric, varied considerably between studies. These methodological details, where available are summarised in the Appendix, but in many studies this data was not given.

Results of the individual studies are summarised in Table 1. Although these are considerable inconsistencies, studies at temperatures of 40°C or less (where it is unlikely that there is any lethal action of heat) suggest LRs due to the dilution effect of rinsing range from around 0.4 to 2.8 log. The exceptions are the data of Sidwell *et al.* indicating LR values up to 6 and the data of Lakdawala *et al.* indicating LRs of 3.6 and 4.9. In studies where laundering in the presence and absence of detergent was compared, in most, but not all, cases the effect of dilution was enhanced by the presence of detergent. These data are also shown in Table 1 for comparison. This effect is likely to increase as the laundering temperature increases.

Although domestic laundering conditions vary considerably, based on a typical domestic laundry cycle, it is possible to estimate the theoretical log reduction (LR) which could be achieved through dilution during laundering if all organisms were detached from the fabric. The following represent 2 typical laundry cycles used in the domestic setting:

- HOTPOINT 30°C/ eco wash/ 1600rpm spin/ 2Kg load/ cotton load. Wash water volume taken in = 11 litres, Rinse 1 = 14.5 litres & rinse 2 = 14.9 litres
- ZANUSI 40°C/ 900 rpm spin/ 2Kg load/ synthetics load = Wash water volume taken in = 14.6 litres, Rinse 1 = 12.5 litres, rinse 2 = 8.5 litres, & rinse 3 = 8.5 litres

Based on the assumption that the volume of water retained by a laundry load at the end of each spin cycle is around 0.5L, these wash and rinse cycles could produce up to 4.3 LR in contamination levels on fabrics.

Details of the effects of dilution as determined from individual studies of laundering in the absence of detergent are as follows:

- **Blaser *et al.* 1984⁷** and **Smith *et al.* 1987⁸** used naturally contaminated laundry to study levels of bacteria recovered in wash effluent from cycles done with or without and laundry chemicals. Blaser *et al.* calculated that the LR due to dilution alone in the number of microorganisms present in rinse water should theoretically be 2.69. From studies of rinse water from sheets, the actual mean decrease from the peak level to

the level at the end of the cycle was of the order of 2.68 log. Similarly, rinse water counts from terry cloth items indicated a mean decrease of 2.84 log.

- Smith *et al.* evaluated laundering at 31°C with no detergent. Comparing the levels of bacteria in the wash water at the beginning and end of the cycles (2 flush and 2 rinses) it was estimated that the LR due to rinsing was about 1.5 to 1.8.
- **Jaska and Fredell 1980**⁹ found that the LR of *Staphylococcus aureus* on fabric swatches by laundering in the absence of detergent increased as wash temperatures increased. At 27, 38, 49 and 60°C respectively, LR was estimated as 0.38, 1.91, 5.76 and >6.17.
- **Davis and Ainsworth 1989**¹⁰ and **Ainsworth and Fletcher 1993**¹¹ found that laundering of polyester cotton impregnated with *Enterococcus faecalis* in the absence of detergent at 50°C produced LR values of the order of 2.4 and 4.5, although the bactericidal action of heat at 50°C may have contributed to the observed effect.
- In their study of washing cycles from different European countries, **Terpstra *et al.* 2003**¹² compared the hygiene effectiveness of a 40°C cotton programme with that of the same programme with an extra rinse. The results show that an extra rinse increased the LR by more than 1 log unit on naturally soiled laundry.
- **Lakdawala *et al.* 2011**¹³ found that the LR of *Acinetobacter baumannii* inoculated onto swatches and laundered with detergent at 30 and 40°C was equivalent to that produced by water rinsing alone (2.1 to 3.6). For *S. aureus* the LR at 30° and 40°C was >7 compared with 2.6 to 4.9 for water washing only.

Three studies have evaluated dilution during laundering of fabrics contaminated with viruses:

- **Sidwell *et al.* 1971**¹⁴ studied laundering at 21 to 27°C, 38 to 43°C and 54 to 60°C using poliovirus inoculated onto a range of fabrics. The extent of the reduction due to dilution increased as the laundering temperature increased.
- **Heinzel *et al.* 2010**¹⁵ evaluated laundering at 30°C against poliovirus inoculated onto cotton swatches. Where swatches were laundered in tap water only, the residual virus load on swatches was found to be 5.3 log, after laundering (LR 2.7).
- **Gerhardts *et al.* 2009**¹⁶ studied laundering of cotton swatches inoculated with MS2 bacteriophage at 40°C (20 min cycle) with or without detergent (type of detergent not stated). Laundering in the absence of detergent produce LR values of 2.82 and 2.57 for swatches inoculated with 10 and 3 log pfu respectively.

5.2 THE EFFECT OF WATER TEMPERATURE

Temperature affects microbial reductions on fabrics during laundering by facilitating physical removal, accelerating chemical inactivation if a bleach is present, and thermal inactivation when above a threshold level. This review identified 25 studies which give insights into the effect of temperature on effectiveness of laundering. With the exception of the studies of Christian *et al.* 1983¹⁷, Blaser *et al.* 1984⁷ and Smith *et al.* 1987⁸, which focus on the effect of chlorine bleach, the data consistently show that numbers of organisms surviving the laundering process increase as the laundry temperature decreases. The results of these various studies are summarised in Table 2 and are as follows:

- In early studies using fabric inoculated with *S. aureus*, data showed reductions in effectiveness of laundering with decrease in laundry temperature. **Wicksell *et al.* 1973**¹⁸ found that the LR decreased from 4 to 1.5 as the temperature was decreased from 68 to 24°C, whilst **Walter *et al.* 1975**¹⁹ found that the LR decreased from 6-7 to 3-4.3 as the temperature was decreased from 49° to 38°C. Similarly **Jaska and Fredell 1980**⁹ indicated that the LR decreased from >4 at 49°C to <1 at 27°C.



- **Cunliffe et al. 1988**²⁰ tested 2 household washing powders against test pieces inoculated with *E. faecalis* laundered at 15 and 30°C. For the non ionic detergent the number of surviving organisms on the test piece was higher at 15°C than 30°C, although the biological powder appeared equally effective at both temperatures. Since initial counts were not stated it was not possible to determine LRs.
- **Davis and Ainsworth 1989**¹⁰ studied the action of a heavy duty detergent powder used for laundering cotton swatches impregnated with *E. faecalis* at 15°C and 50°C. The hygienic performance was substantially better at 50°C (LR 6.5) than at 15°C (LR1.5).
- In a further 1993 study **Ainsworth and Fletcher**¹¹ compared the action of a heavy duty detergent (most likely the same product as above) and a heavy duty liquid detergent at 30°C and 50°C using swatches impregnated with *E. faecalis*. Both for the powder with activated bleach and a liquid detergent decontamination from *E. faecalis* was substantially better at 50°C (LR 7.0) than at 30°C (LR 5.0).

Since the IFH review of the effectiveness of laundering was prepared in 2002 several new studies have been published:

- **Terpstra et al. 2003**¹² carried out an extensive study of laundering of naturally contaminated laundry items (diapers, dishcloths, socks and handkerchiefs), using products, dosages and temperatures most commonly employed in 4 different European countries. After laundering, items were tested to determine total viable counts (TCs), and counts of Enterobacteriaceae (EC). In a first set of experiments laundering at 40° and 60°C was compared and in the second set, laundering at 15° and 30°C was determined. The range of LRs calculated using the data presented in the Appendix was as follows:

	Log reductions in counts on diapers and cloths during laundering – range of values determined from data for studies carried out in 4 European countries			
	First set of experiments		Second set of experiments	
	60°C	40°C	30°C	15°C
Based on TCs	4-8	1-5	1-3	0.5-3
Based on ECs	6-9	2-6 (in one study an LR value of 8 was recorded)	2-5	1.5-4

Statistical analysis showed that, for the first set of trials, the hygienic quality of the laundered fabrics was significantly better after laundering at 60°C than at 40°C. However, it must be borne in mind that, in all countries, laundering at 60°C was done with an AOB -based product, whilst for all bar one study at 40°C, a non-AOB detergent was used. Although the second trial suggest some further loss of effectiveness between 30°C and 15°C, the authors do not state whether the difference was statistically significant.

- **Lichtenburg et al. 2006**²¹ reported 2 studies using cloths inoculated with *Enterococcus Faecium* and *S. aureus* which were laundered at 30°, 40° and 60°C using 3 different detergents. After using detergent powder (containing AOB), no residual contamination was detected, even at 30°C, indicating >3 log reduction at all temperatures. Using a detergent liquid, although LRs of 3 or more were obtained at 60°C, LRs at 30° and 40°C were of the order of 2.3 -2.4. Using a light-duty detergent, LRs were 2 and 2.5 at 40°C and 0.5 and 1.2 at 30°C for *E. Faecium* and *S. aureus* respectively. In a second set of experiment suspensions for contaminating fabrics were created cultivating residual water from the machine for several days at room temperature. At 60°C LRs of 2.7 to 3 was demonstrated for all detergents. There was

some reduction in effectiveness as temperature was decreased although, the results were somewhat inconsistent.

- Two studies were recently carried out at UCL London, to evaluate infection risks associated with laundering of healthcare workers uniforms at low temperatures in their own homes. **Patel et al. 2006**²² used cloth samples inoculated with *S. aureus* at 10^8 to 10^{10} cfu and dried. Samples were laundered together in a 40°C and 60°C wash cycle using non-biological washing powder containing AOB (confirmed by pers comm.). For both the 40°C and 60°C cycles, despite the high inocula, *S. aureus* was not isolated from samples after the wash cycle. In a 2011 study **Lakdawala et al.**¹³ studied laundering of fabric swatches using a biological detergent and a nonbiological detergent without AOB (confirmed by pers comm.). Inocula were designed to reflect that found on naturally contaminated clothing and were lower than that used by Patel et al. 2006 (10^6 – 10^7 compared with 10^8 – 10^{10}). Effectiveness increased with temperature between 40 and 60°C producing >5 LR at 60°C for both organisms. For *A. baumannii*, the data suggest that the LR at 30° and 40°C (2.1 to 3.6) is equivalent to that produced by water rinsing alone. For *S. aureus*, the LR at 30° and 40°C was >5.
- **Linke et al. 2011**²³ studied the hygiene effectiveness of machine laundry processes on cotton samples contaminated with *S. aureus*. Although premium detergent cycles (AOB-based) at 40°, 60° and 80°C produced 8 LR in contamination, cycles at 30°C produced only 3 LR. For non-premium (non AOB-based) liquid colour detergent and gel detergent, although 60°C cycles produced greater than 4 LR, 30°C cycles, even with pre-wash, produced less than 1 LR.
- **Bellante et al. 2011**²⁴ studied sheets contaminated with Actimel yoghurt containing 10 log *lactobacillus casei* laundered at 30°, 40° and 60°C using either a “full industrial detergent” (with AOB) or a non-AOB colour detergent. Contamination levels were determined using contact plates. Before laundering, plates showed >2000 cfu per plate which meant it was not possible to calculate the log inoculum. After laundering at 60°C no lactobacilli or other microbes could be detected, regardless of whether a universal laundry detergent or a color detergent (non AOB) was used. After laundering at 40°C and 30°C using AOB-based laundry detergent no test bacteria could be detected, but very small numbers (0-16 per plate) of other bacteria were detected. By contrast, using the colour detergent, after laundering at 40°C small numbers of lactobacilli (0-8 per plate) and 0-16 per plate of “other bacteria” were detected, and after laundering at 30°C both lactobacilli (128-2000 per plate) and 60-156 per plate of “other bacteria” were detected.
- In further studies (**Bellante et al. 2011**²⁴) carried out in private homes, where textiles (Linens, T-Shirts and terry towels) contaminated with Actimel yoghurt containing *Lactobacillus casei* were laundered under a range of conditions, numbers of bacteria surviving the laundering process increased as the laundry temperature decreased.

Studies demonstrating the reduction in effectiveness of laundering on virus-contaminated fabrics at lower temperatures are described in section 5.4.

As stated above, by contrast with the above examples, the data of **Christian et al. 1983**¹⁷, **Blaser et al. 1984**⁷ and **Smith et al. 1987**⁸ suggests that temperature has little or no effect on hygiene effectiveness of laundering. These studies, using naturally contaminated fabrics, all carried out in the 1980s, were specifically designed to determine whether the bacteriological quality of fabrics cleaned in a hospital laundry could be maintained at wash temperatures lower than 75°C by using “economically reasonable formulas and wash conditions”. In all 3 studies however, the process included addition of chlorine bleach at concentrations up to 125 to 250 mg/l. In studies by Christian et al. and Smith et al., in some cases a higher chlorine concentration was used

at lower compared with higher temperatures. It is thus not possible to make a valid assessment of the independent effect of temperature from these studies.

5.3 THE EFFECT OF LAUNDRY PRODUCT FORMULATION - BLEACH-BASED AGENTS

During laundering, chemical inactivation of microbes on fabrics can be achieved using various bleach components. Normally today oxygen bleaches (persalts) with a low temperature activator are used or, as is common in some countries, chlorine-based bleaching agents are added to the wash load. General-purpose laundry detergent powders typically contain a bleach system, usually based on active oxygen delivered via percarbonate together with a bleach activator such as TAED. The primary purpose of the active oxygen bleach (AOB) is to achieve better cleaning and improved whiteness of the laundry. Oxygen-based bleaches however, also produce some chemical inactivation of bacteria, fungi and viruses, and the surfactant itself will also exert some chemical inactivation action against certain species. The extent of this action will depend on the concentration, wash temperature, pH, level of soiling etc. The rate and extent of release of active oxygen and thus the microbiocidal action decreases as the wash temperature decreases, but bleach activator manufacturers claim that effective bleaching action can be delivered even at temperatures down to 20°C.²⁵

Examples of the most commonly used AOBs are tetraacetythylenediamine (TAED)/ persalt combinations (now normally percarbonate but historically perborate) which release peracetic acid on contact with water in a temperature dependent manner. If a domestic laundry product is “oxygen bleach-based”, the term “oxygen-based bleaching agent” is listed as one of the ingredients on the pack. As summarised in the table below, as a rule, powders and tablets are bleach-based, but liquids, and products used for “coloureds” are not.

	Powder / Tablets					Liquids				
	Bio		Non-bio		Colour	Bio		Non-bio		Colour
'bleach'	+	+	+	+	-	-	-	-	-	-
Enzymes	+	+	-	-	+/-	+	+	-	-	+/-

Assessing the separate contribution of AOB action on the hygiene effectiveness from the available data is difficult not least because in many of the studies evaluated in this review (Jordan *et al.* 1969²⁶, Sidwell and Dixon 1969²⁷, Wicksell *et al.* 1973¹⁸, Walter and Schillinger 1975¹⁹, Jaska and Fredell 1980⁹, Cunliffe *et al.* 1988²⁰, Gerba *et al.* 2001³¹, Gerba and Kennedy 2007²⁸) it was not stated (or possible to determine by personal communication) whether the detergent did or did not contain an AOB. Since early studies (probably up to the late 1970s/ early 80s) were probably carried out before introduction of bleach activators such as TAED (these detergent relied on release of H₂O₂ from perborate which is slow below 70°C) it is unlikely that these studies involved AOB-containing products.

Of the studies which specifically indicate that AOB containing detergent was used (Terpstra *et al.* 2003, Lichtenburg *et al.* 2006, Block *et al.* 2001, Linke *et al.* 2011, Heinzl *et al.* 2010, Bellante *et al.* 2011, Vossebein 2013,²⁹ Lucassen and Bockmuhl 2013³⁰) only some (Terpstra *et al.* 2003, Lichtenburg *et al.* 2006, Linke *et al.* 2011, Bellante *et al.* 2011, Vossbein 2013, Lucassen and Bockmuhl 2013) directly compared AOB with non AOB detergent, or the extent to which the effectiveness of an AOB relative to a non AOB detergent decreases as laundry temperature decreases. Although the studies of Terpstra *et al.*, Linke *et al.*, Bellante *et al.*, and Vossebein consistently show that use of an AOB product enhances the hygiene effectiveness, the studies of Lichtenburg *et al.* 2006 and Lucassen and Bockmuhl are inconsistent. It must be remarked that Lichtenburg *et al.*



report use of liquid products containing bleach: such products are understood to be unusual. Results of the individual studies are summarised in Table 2 and are as follows:

In studies comparing effectiveness of laundering at **60°C**:

- **Linke et al. 2011**²³ showed that laundering of fabrics contaminated with *S.aureus* using an AOB detergent produced a LR >8 logs, compared with 4.22 where a non AOB colour detergent was used.
- **Lichtenburg et al. 2006**²¹ found that, in laundering of fabrics contaminated with *S.aureus* and *E.faecalis*, both AOB and non AOB formulations produced >3LR which was the upper limit of detection of the method.
- **Bellante Engel, Hatice, Neuman, Okyaya, Peters and Vossbein 2011**²⁴ carried out a study using sheets contaminated with Actimel yoghurt containing *L. casei*. After laundering at 60°C no lactobacilli or other microbes could be detected, regardless of whether an AOB or non AOB detergent was used. In this study a laboratory “Wascator” machine was used
- **Vossebein 2013**²⁹ also carried out studies using textiles contaminated with Actimel yoghurt containing *L. casei*. Trials were carried out in standard household washing machines. After washing, laundry was sampled using contact plates. Loggers were used to monitor the temperature profile of the washing programme which showed that the maximum temperature reached was of the order of 46-53°C. The authors concluded that in one of two studies using AOB detergent no yoghurt bacteria were seen on laundered samples, whilst in the other small numbers of contaminants were recovered. By contrast, for textiles laundered with non-AOB detergent numbers of contaminants was not significantly reduced
- **Lucassen and Bockmuhl 2013**³⁰ evaluated laundering of cotton guest towels which had been used regularly for 3 days in the sanitary facilities of the Rhine-Waal University. Towels were sampled using agar contact plates. Mean counts on towels before laundering was 53 (Max 800, min 0). The temperature profile of the laundry program was monitored using a sensor which showed that the maximum temperature was 50°C only, which declined to around 46°C during the 20 min wash cycle. The LR was estimated as 1.75 (98.2%) and 1.92 (98.8%) for non AOB and AOB cycles respectively

In studies comparing effectiveness of laundering at **40°C**:

- **Terpstra et al. 2003**¹² found higher LR (6-8 compared with 2-5) using the typical Spanish product, which was a powder containing AOB, than for products from the other countries which did not containing a bleach. The authors suggested however that this increased performance was due to an extra rinse, triggered in the Spanish test by high foam levels.
- **Lichtenburg et al. 2006**²¹ showed that use of an AOB detergent produced a >3 LR, whilst a non AOB detergent produced only a 2 to 2.5 LR.
- Data from **Linke et al. 2011**²³ show that an 8 LR is obtained when an AOB product is used, compared with <1 LR if a non AOB product is used.
- **Bellante, Engel, Hatice, Neuman, Okyaya, Peters and Vossbein 2011**²⁴ found that, after laundering with AOB detergent, no lactobacilli were detected, but small numbers (0-16 per contact plate) of other bacteria were found. By contrast, after laundering with non AOB colour detergent, both small numbers of lactobacilli (0-8 per) and 0-16 per contact plate of other bacteria were detected.
- **Vossebein 2013**²⁹ also carried out a study using textiles contaminated with Actimel yoghurt containing *L. casei*. After washing, the laundry was sampled using contact plates. Loggers used to monitor the temperature profile of the washing programme showed that the maximum temperature reached was of the order of 35-40°C. The authors concluded that for both studies using AOB and non AOB detergent the number of contaminants was not significantly reduced



- **Lucassen and Bockmuhl 2013**³⁰ evaluated laundering of cotton guest towels which had been used regularly for 3 days in the sanitary facilities of the Rhine-Waal University. Towels were sampled using agar contact plates. The temperature profile of the laundry program was monitored using a sensor which showed that the maximum temperature the maximum temperature was around 38-39°C which declined to around 37°C during the 20 min holding period. Results showed that the LR in contamination was estimated as 0.54 (71%) and 2 (99%) for the non AOB and AOB cycles respectively.

In studies comparing effectiveness of laundering at 30°C:

- **Linke et al. 2011**²³ showed that the LR using AOB detergent was 3.0, but <1 when using non AOB detergent.
- **Lichtenburg et al. 2006** showed that use of AOB detergent produced a >3 LR reduction, whilst non AOB detergent produced only 0.5 to 1.2 LR.
- **Bellante et al. 2011**²⁴ found that, after laundering with AOB product at 30°C, no lactobacilli were detected, but small numbers (0-16 per contact plate) of other bacteria were found. By contrast, after laundering with colour detergent both lactobacilli (128-2000) and also 60-156 per contact plate of other bacteria were detected.
- By contrast, no impact of product formulation at 30°C or less was demonstrated by **Terpstra et al. in 2003**.¹² These workers studied TCs and ECs on naturally contaminated diapers, cloths, handkerchiefs and socks. In 2 of 4 trials an AOB detergent was used whilst in the other 2 trials non AOB detergent was used. After laundering at either 15°C or 30°C, there was no apparent difference between the LRs produced (or the extent of cross contamination to sterile fabrics) by AOB and non AOB detergents at either temperature.
- **Lucassen and Bockmuhl 2013**³⁰ evaluated laundering of cotton guest towels which had been used regularly for 3 days in the sanitary facilities of the Rhine-Waal University. The temperature profile of the program was monitored using a sensor which showed that the maximum temperature was 50°C which declined to around 28-29°C but then was largely sustained during the 55 min holding period. Results showed that the LR in contamination was estimated as 0.3 (50%) and 0.14 (18%) for the non AOB and AOB cycles respectively

As an overall conclusion from their study comparing laundering with AOB and non AOB detergents, Terpstra *et al.* 2003¹² stated "a significant effect of (activated oxygen) bleach on the hygienic quality of laundry is found (ANOVA-One Way, $\alpha = 0.05$). The hygienic quality improves when detergents with bleaching agents are used. This was also confirmed by an additional test at 60°C without bleaching agents (although the results are not presented). The effects of temperature and bleach interact. When a detergent contains bleach and the washing temperature is increased, the hygiene result improves."

It should be noted that the studies of Lichtenburg *et al.* 2006²¹ are inconsistent. Out of 2 studies, the first, using swatches inoculated with *E. faecium* and *S. aureus*, indicated that use of AOB detergent was associated with increased hygiene effectiveness, but the second, using swatches contaminated with suspensions cultured from residual laundry wash water, were inconsistent, showing little evidence of potentiation by AOB.

5.3.1 Use of chlorine bleach

Chlorine bleach has been used for many years in laundering, not only for its bleaching action, but also its disinfectant activity. The effect of addition of chlorine bleach to machine laundry cycles is demonstrated in a number of studies carried out in the 1970s and 80s. The purpose of these studies were to determine whether the bacteriological



quality of fabrics cleaned in a hospital laundry could be maintained at lower wash temperatures,

Studies by Walter and Schillinger 1975¹⁹, Christian *et al.* 1983¹⁷, Blaser *et al.* 1984⁷ and Smith *et al.* 1987⁸ indicate that, although hygiene effectiveness is temperature dependent in the absence of bleach, in the presence of hypochlorite bleach, water temperature does not seem to affect residual bacterial counts in fabrics after laundering i.e. both hot and cold water in combination with a bleach cycle are equally successful in reducing bacteria counts:

- Using fabrics contaminated with *S. aureus* laundered using non ionic detergent, **Walter and Schillinger 1975**¹⁹ showed that, whereas, at 38°C the LR was increased from 2.85 to 7.05 by addition of 69-131 mg/l chlorine bleach, at 49°C LR values were 6.68 and 7.1 in 5-7 both in the presence and absence of bleach (82mg/l).
- Using hospital soiled laundry, **Christian *et al.* 1983**¹⁷ studied the relationship between effectiveness of laundering and chlorine at concentrations from <50, to 250 ug/ml. Significant differences in total counts were found. The lowest chlorine concentration category was represented by the lowest percentages of no growth and the highest median densities. It was found that wash conditions at 47.8-60°C were equal to or more effective than washing at high temperatures, and it was concluded that this was due to different formulation usage at low temperatures which delivered higher chlorine concentrations. i.e differences were not due to temperature
- Using soiled hospital laundry, **Blaser *et al.* 1984**⁷ determined bacterial counts after laundering at 71°C and 22°C with addition of 125 mg/l chlorine after 19 min of laundry cycle. Low-temperature washing resulted in fewer residual cells for sheets, and high-temperature washing resulted in fewer residual cells for towels.
- Using naturally contaminated sheets and terry cloths, where samples were taken throughout the laundry cycle, **Smith *et al.* 1987**⁸ found that addition of chlorine bleach (100-120ppm) during laundering rendered the counts similar in the two temperature processes. A separate study showed that a 66°C wash reduced bacterial counts by 3 log. By adding bleach (100-120ppm), a similar LR could be achieved at 31°C.
- Using swatches inoculated with a range of bacterial species (*S. aureus*, *E. coli*, *S. typhimurium* and *Mycobacterium fortuitum*), **Gerba *et al.* 2001**³¹ showed that the LR after laundering at 22°C was around 2.1 to 3.4, the LR, and was increased to >5 up to 6.05 by addition of 114-125mgm/litre chlorine.

A number of studies have evaluated the impact of bleach on laundering of fabrics contaminated with viruses:

- Using soiled nappies from infants who had received polio vaccine, **Jordan *et al.***²⁶ tested the use of sodium hypochlorite at 45°C and 55°C. Poliovirus was not inactivated after 2 minutes exposure to water at 45° but was inactivated at 55°C. However the addition of 200ppm available chlorine was effective in inactivating poliovirus at 45°C.
- **Gerba and Kennedy 2007**²⁸ studied the effectiveness of the laundry cycle in removing enteric viruses (adenovirus, rotavirus and hepatitis A virus). The water temperature was 20 to 23°C. The powdered detergent was said to consist of linear alkyl benzene sulfonate, sodium carbonate and alkyl sulfate. The authors calculated that the wash and rinse cycle, with detergent, produced a 92 to 99%, (1.1-2.0 log) reduction. Addition of bleach (114 to 125 mg/litre, typical of US household laundry) resulted in further virus reduction by at least 99.99% (4 log) after washing (Table 2).

From a review of 11 reports published from 1938-1981 (including those cited above), Battles and Vesley 1981³² concluded that that chlorine bleach greatly enhances the lethal effect of heat and that, for laundering linens from health care facilities, use of 60°C with



addition of chlorine bleach is recommended. The important role of chlorine bleach in hospital laundering was also reviewed by Belkin 1998.³³

5.4 EFFECTS ON VIRUSES.

In home and everyday life settings, effectiveness against viruses is key since many common infections transmitted in the home are viral including enteric viruses such as rotavirus, norovirus and adenovirus, and respiratory viruses such as rhinovirus, influenza and respiratory syncytial virus. A number of studies report on the effectiveness of laundering on viral contamination of fabrics. These involve a range of species including non-enveloped viruses such as polio, adeno, rota and hepatitis A virus, and enveloped viruses (i.e viruses which bear a lipid outer coating) such as vaccinia virus. Results of individual studies are summarised in Table 3 and are as follows:

- **Jordan et al. 1969**²⁶ studied laundering of soiled nappies from infants who had previously received a polio vaccine, using soap granules or detergent at 45°C and 55°C. Poliovirus was not inactivated after 2 minutes exposure at 45° but was inactivated at 55°C. Addition of 200ppm available chlorine was effective in inactivating poliovirus at 45°C after 10 min.
- **Sidwell and Dixon 1969**⁸ reported studies in which polio and vaccinia virus were inoculated onto cotton sheeting and laundered at 21-26C in a wash-rinse cycle using an anionic and non ionic detergent. Using anionic detergent, the mean titre of poliovirus was reduced by 2 log, and of vaccinia by about 4 log to undetectable levels. Higher effectiveness against vaccinia virus is not unexpected because it is an enveloped virus, the lipid envelope making it susceptible to disruption by the detergent. With non ionic detergent it was concluded that virus titre reduction was over 2 log although a significant quantity of virus remained on the fabric. The authors concluded that the virus reduction were primarily the result of physical removal rather than virus inactivation,
- In a later study involving only the more resistant poliovirus **Sidwell et al. 1971**¹⁴ studied the effectiveness of laundering of a range of fabrics at 21-27°C; 38-43°C; and 54-60°C using anionic or non-ionic detergent. Virus titres were reduced considerably during laundering, The authors concluded that heat was one of the most important factors, as shown by the fact that reductions were most marked in hot-water laundering (3.6-5.8LR) with little detectable virus remaining on fabrics. Less differences were seen between the effects of warm and cold water (LR of 2.4-6.3 and 1.2-5.6 respectively), although the data suggests that laundering in warm water was somewhat more effective than cold water.
- **Wicksell et al. 1973**¹⁸ found that laundering at 57°and 68°C produced up to 4 LR in counts of T3 phage inoculated onto swatches. Although effectiveness decreased with decreasing temperature, LRs of 3 or more were recorded at temps of 24, 35 and 46°C, and at all temperatures the phage were found to be more sensitive than *S. aureus*.
- **Gerba and Kennedy 2007**²⁸ studied the effectiveness of the laundry cycle in removing enteric viruses (adenovirus, rotavirus and hepatitis A virus). The water temperature was 20° to 23 °C, the average temperature of a cold-water wash in the US. The powdered detergent was said to consist of linear alkyl benzene sulfonate, sodium carbonate and alkyl sulfate. The authors calculated that the wash and rinse cycle, with detergent produced a 92 to 99%, (1.1-2.0 log).
- **Gerhardt et al. 2009**¹⁶ studied laundering of cotton swatches inoculated with MS2 bacteriophage and soiled with artificial faeces. Swatches were laundered at 40°C (20 min cycle) with or without detergent (type of detergent not stated). For inoculum sizes of 10 and 5 log, the LR values were 6.82 and 3.96 respectively.
- **Heinzel et al. 2010**¹⁵ evaluated laundering at 30°C against poliovirus inoculated onto cotton swatches. A commercially available heavy duty AOB powder detergent was

used. Where contaminated swatches were laundered in tap water only (calculated load of poliovirus of 7.98 lg/swatch) the average residual virus load on swatches was found to be 5.3 log, after laundering (LR 2.7). In contrast, when using the laundry detergent the virus particles were inactivated to a level below the detection limit, i.e. a log reduction >5. The authors expressed concern however that the tests were run without organic challenge. They suggest that this may explain why, in *in vitro* tests of effectiveness out in parallel, 40°C was found as minimum temperature for full virucidal effectiveness (in the presence of 0.3% BSA), whereas the *in situ* results suggest full antiviral effectiveness against poliovirus at 30°C.

- **Fijan et al. 2006**³⁴ carried out a study of rotaviral RNA in water from a hospital laundry. Rotaviruses are known as major causal agents of diarrhoea in humans. RT-PCR techniques were used to determine the presence of rotaviral RNA in water samples. The results show that rotaviral RNA was found in wastewater after the washing process, thus that the laundering procedure did not achieve total elimination of rotavirus from fabrics under the hospital laundering conditions which were used

5.5 EFFECTS ON FUNGI

Effectiveness against fungi is important. In developed countries *T. rubrum* accounts for 70% of all dermatophytoses (including athlete's foot) in humans. Textiles (including socks and stockings) in direct contact with affected skin are major pathogen carriers and only a few viable spores are required for skin infection.³⁵ For people with vaginal candidiasis tight-fitting garments may become contaminated, and can cause reinfection after successful therapy.³⁶ Studies on effectiveness of laundering on fungal contamination is summarised in Table 4 and are as follows:

- **Blaser et al. 1984**⁷ evaluated microbes recovered from used naturally contaminated fabrics after laundering. Using standard methods 149 representative colonies were selected and identified, but no fungi were found.
- **Block et al. 2001**³⁷ found that laundering at 30°C with an activated bleach detergent produced a marginally lower LR against *C. albicans* and *Trichophyton mentagrophytes* than against *S. aureus*. In the presence of soil, LRs of 3.1, 4.2 and 3.9 were recorded against *S.aureus* compared with 2.6, 2.2 2.4 against *C. albicans*, and 0.8, 2.2 and 1.3 against *T. mentagrophytes*. In absence of soil the LR for *S. aureus* was 7.2 compared with 3.9 and 4.1 for *C. albicans* and *T. Mentagrophytes* respectively.
- **Fijan et al. 2007**³⁸ studied laundering of fabrics contaminated with bacterial and fungal species including *C. albicans*. LR values increased as laundry temperature increased. At 45°C, *C. albicans* was marginally more resistant than *S. aureus*, (LR values of 2.0 and 2.11-2.58 respectively). By contrast, whereas *E. faecium*, *S. aureus*, *E. aerogenes*, and *P. aeruginosa* survived laundering at 60°C, *C. albicans* did not.
- **Hammer et al. 2010**³⁵ studied the survival of *Trichophyton rubrum* and *C. albicans* in washing procedures at different temperatures. Washing programs at 30°C and 60°C and washing powders of different suppliers were used. *C. albicans* was eliminated completely in all washing procedures both on textiles and in the rinsing water. *T. rubrum* was inactivated at 60°C, while a significant part survived at 30°C. Using radio-labelled *T. rubrum* it was found that about 10% of the infectious material was transferred from contaminated textiles to sterile textiles during storage in a clothes basket simulation indicating a high infection risk during storage.
- **Ossowski and Duchmann 1997**³⁹ showed *T. rubrum* was eliminated in a 30°C washing process (compared with Hammer et al. who found that 60°C was essential for complete inactivation of the pathogen, even when using washing powders with bleaching agents).
- **Ossowski and Duchmann 1999**³⁶ demonstrated that *Candida* spp could survive machine washing at 30°C. After laundering at 40°C, ability to survive varied according

to the strain of *Candida* and the type of detergent. No survivors were detected after washing at 60°C.

5.6 EFFECTS ON BACTERIAL SPORES

For the most part, investigations of the effectiveness of laundering were carried out using vegetative bacterial strains. It is known that bacterial spores can survive wash temperatures higher than 70°C. Only one study included in this review was carried out with spore-forming organisms. **Wicksell et al. 1973**¹⁸ found that laundering at 57° and 68°C produced approx 1.5 LR in counts of *Bacillus stearothermophilus* spores inoculated onto swatches (initial count log 4.68) compared with 4.5 LR for *S. aureus*.

Insights on the ability of spores to survive laundering processes at different temperatures also come from studies of residual survivors on naturally contaminated fabrics:

- **Blaser et al. 1984**⁷ evaluated types of microbes recovered from used naturally contaminated fabrics after laundering. In all, 149 representative colonies were selected and identified. Only three species of gram negative bacilli, representing 2.0% of the sample, were isolated and identified, all three were present after low-temperature wash cycles. *Bacillus* species accounted for 38 (52.8%) of 72 and 41 (53.2%) of 77 of the identified bacteria from the low- and high-temperature wash cycles, respectively.
- In the studies of **Terpstra et al. 2003**¹² involving naturally contaminated items (diapers, dishcloths, socks and handkerchiefs) laundered, using common European washing processes, survival on laundered items was determined and also transfer of microbes to sterile items included in the wash load. The results suggest that spore-forming bacilli can survive on naturally contaminated fabrics at levels up to 2 log cfu/4.7cm² even where fabrics are laundered at 60°C with an AOB detergent. Results indicate that, in 2 out of 3 samples laundered at 60°C with AOB detergent, bacilli were transferred to sterile samples giving counts up to 2 log cfu per 4.7cm² sample. In 2 out of 3 samples laundered at 40°C with a non AOB powder, bacilli were transferred to sterile samples giving counts of 1 to 2 log cfu per 4.7cm². In none of 4 samples laundered at 30°C (2 with AOB powder, 2 with non AOB powder) bacilli were transferred. In 3 out of 5 samples laundered at 15°C (3 with AOB powder, 2 with non AOB powder), bacilli were transferred to sterile samples giving counts of 1-2 log cfu per 4.7cm² sample.
- In a hospital-based study **Nicoles 1970**⁴⁰ evaluated contamination levels on naturally contaminated fabrics after laundering which included ironed towels, uniforms, napkins, dish towels etc. Residual survivor counts of 7 or more logs were isolated, but these were mainly gram-positive spore-formers.
- **Lakdawalla et al. 2011**¹³ evaluated whether *Clostridium difficile* could be detected on bed linen following a commercial washing process at 71°C, 3 minutes followed by a steam press. Six patients were identified as having diarrhoea and a positive stool toxin test. Up to 10¹–10³ cfu/100cm² could be recovered from the bed linen. The ribotype of the patients' isolates matched the ribotype isolated post laundry. In one case an additional ribotype was isolated.

Although spore-forming environmental bacteria, such as *Bacillus* spp. have been found to survive the laundering process even at high wash temperature; apart from *C. difficile*, these bacteria are not generally associated with community infections. However, up to 3% of healthy adults carry *C. difficile* asymptomatically, and up to 60% of infants during first few months of life, although it is not known what proportion are carrying toxin-producing strains.



5.7 THE EFFECTS OF SOILING ON EFFECTIVENESS OF LAUNDERING

A likely source of the variability between data obtained from different studies is the differences in nature and amount of “soiling” added to the laundry load. Tables 2 and 3 summarise the types of soiling used in different studies. In all cases, it appears that the test strains were prepared in nutrient medium with the following additions:

- In the studies of Sidwell *et al.* 1969¹⁴, 1973²⁷, Wicksell *et al.*¹⁸, Walter and Schillinger¹⁹, Jaska and Fredell⁹, Heinzl *et al.*¹⁵ and Patel *et al.*²², no additional soil was added.
- In the studies of Linke *et al.* 2011²³, Block 2001³⁷, Terpstra *et al.* 2003¹² and Lichtenburg *et al.*²¹ defibrinated sheeps blood (20-40g) was distributed in the load before laundering.
- Lakdawala *et al.*¹³ used swatches inoculated by soaking in 10 ml of bacterial suspension in 3.5% bovine serum albumin, but no soil was added to the load.
- Gerba *et al.* 2001³¹, 2007²⁸ used a synthetic organic load as detailed in the Appendix
- Fijan *et al.* 2007³⁸ used various materials; Gerhardtts *et al.*¹⁶ used artificial faecal soiling.

Very little systematic work has been carried out to determine the extent to which different soiling levels may or may not affect the hygiene effectiveness of laundering:

- **Block *et al.* 2001³⁷** found that if the laundering at 30°C using TAED/sodium percarbonate detergent was repeated without the inclusion of 37.5g defibrinated sheeps blood, the LR value was increased although the extent of the increase varied for different species:

LR after laundering with TAED/percarbonate detergent in presence and absence of soil					
	<i>S. aureus</i>	<i>E. faecium</i>	<i>K. pneumoniae</i>	<i>C. albicans</i>	<i>T. mentagrophytes</i>
Soil	4.2	2.6	3.2	2.2	2.2
No soil	7	3	3.4	3.9	4.1

- **Heinzl *et al.* 2010¹⁵** carried out suspension tests against viruses suspended in hard water with low (0.03% w/v BSA) and high (0.3% w/v BSA + 0.3% w/v erythrocytes) protein loads at different temperatures (see appendix for results). They concluded that, when using the recommended detergent dosage (0.4%), sufficient LR values (judged as 3-4 LR) could be achieved at 40°C provided that “protein stress” was low. For high protein loads, laundering with a detergent concentration of 0.8% was needed to meet these requirements. The authors suggest that this may explain why their *in vitro* suspension tests (carried out in parallel) indicated that 40°C was the minimum temperature for virucidal effectiveness (in the presence of 0.3% BSA), whereas *in vivo* tests with inoculated swatches suggested antiviral effectiveness against Poliovirus at 30°C.

In their report, Terpstra *et al.* 2003¹² state that “in normal laundry the organisms occur in soil aggregates that make them more persistent”. The latter has been demonstrated by Terpstra and Raschle for the household situation. Both found substantially lower disinfection values in tests in which normally soiled laundry was used. In his research Raschle found an increased number of bacteria after washing dirty laundry at 30°C.

5.8 TRANSFER FROM CONTAMINATED ITEMS TO STERILE ITEMS DURING LAUNDERING

A significant concern is that, if laundry processes do not eliminate pathogens from fabrics, these may be transferred to uncontaminated items during laundering. A number

of studies have evaluated the risks by including both contaminated and sterile swatches in the laundry cycle. Where data is available Table 2 indicates conditions under which transfer to sterile items was either facilitated or prevented during the laundry process:

- **Wicksell et al. 1973**¹⁸ demonstrated a correlation between extent of survival of *S aureus* during laundering at different temps and extent transfer to sterile samples during laundering. Transfer of contamination at 68°C was 0.54 against a residual survivor level of 1.2 log (inoculum size 5.52/23 sq cm), whilst for laundry processes at 24°C, residual contamination on sterile samples was 1.48 against a residual survivor level of 3.77 log.
- **Cunliffe et al. 1988**²⁰ demonstrated a correlation between LR of *E. faecalis* during laundering and transfer to sterile samples. There was a greater cross-contamination from infected to sterile test pieces in the wash cycles at 15°C compared with 50°C.
- **Davis and Ainsworth 1989**¹⁰ and **Ainsworth and Fletcher 1993**¹¹ found a correlation between LR of *E. faecalis* (inoculum size 7-8 log/1.6 cm²) and transfer to sterile samples during laundering. In the 1993 study transfer to sterile samples during laundering at 50°C was zero and 1 log, against a residual survivor level of no detectable survivors (>7 and 6.52 LR). At 30°C, residual contamination on sterile samples was 1-2.5 log against a residual survivor level of 2.5 log. For laundering at 15°C, residual contamination on sterile samples was 3.5 log against a residual survivor level of 5.08 log. Cross-contamination to sterile swatches was found at both temperatures but substantially more at the lower temperature.
- **Block et al. 2001**³⁷ scored transfer rates to sterile fabrics out of 10 replicate tests with contaminated fabrics laundered at 30°C (although numbers of organisms transferred was not recorded). For the 3 bacterial strains (*S. aureus*, *Enterococcus faecium* and *Klebsiella pneumoniae*) laundering produced LRs mostly between 1.9 and 4.2 (initial count 8.4 to 9.8) and in most trials transfer was recorded in 10 of 10 replicate tests. In tests with *S. aureus* where an LR of 7.2 was achieved by laundering with an AOB product in the absence of soiling which correlated with transfer to sterile samples in only 7 out of 10 replicate tests. For the fungal strains *C. albicans* and *Trichophyton mentagrophytes* log reductions varied from 0.8 to 4.1. Transfer rates varied from 0 to 9 out of 10 samples but there was no correlation between transfer rates and the LR on contaminated samples.
- Further insights come from studies of **Terpstra et al. 2003**¹² where naturally contaminated diapers and dishcloths were laundered, using common washing processes in 4 European countries. After laundering, items were tested to determine total viable counts (TCs), and counts of Enterobacteriaceae (EC). At the same time, cross contamination to sterile samples included in the wash was also tested to determine TCs, and ECs, Bacillus and *S aureus*. Initial counts before laundering were of the order of 7-9 log for TCs and 6-9 log for Enterobacteriaceae. The extent of the residual contamination on laundered contaminated fabrics was related to the extent of transfer to sterile items.

The first study showed that washing with an AOB powder at 60°C reduced enterobacteria counts to zero (i.e no detectable survivors) in 11 of 12 trials (the 12th trial showed 2 log survivors) although residual TCs of 1-4 logs were recovered from these samples. At 60°C although there was some transfer of bacteria (TCs and spore former bacilli) to sterile samples, transfer of enterobacteria and *S. aureus* was not observed. By contrast, after laundering at 40°C with a non AOB powder, residual log counts of 3-5 of enterobacteria were found together with some transfer of enterobacteria (and on one occasion *S. aureus*) to sterile swatches, with counts up to 3-4 logs and 1-2 logs per 4.7cm² recorded for Enterobacteriaceae and *S aureus* respectively.



Results of the second study, comparing laundering at 15 and 30°C, indicate some further reductions in effectiveness (although these were not statistically significant) and there was some increase in extent of transfer to sterile items at 15°C compared with 30°C. At 30°C, residual counts of Enterobacteriaceae were of the order of 2-5 logs per 4.7 sq cm² after laundering. In all cases, these enterobacteria were transferred to sterile samples at levels up to 2 log (100) per 4.7 sq cm², but no transfer of *S.aureus* was detected. For laundering at 15°C, residual counts of enterobacteria were of the order of 3-5 logs after laundering. In all cases, Enterobacteria were transferred to sterile samples at levels of 1 up to as much as 3 log per 4.7 sq cm² and transfer of 1.5 logs *S. aureus* was detected on one out of 4 sterile samples.

- In the study by **Linke et al. 2011**²³ using AOB, no transfer of *S.aureus* from contaminated to sterile items was detected over the temperature range 30-60°C despite the fact that at 30°C the LR was 3.0. By contrast, where a non AOB powder was used at 30 and 40°C transfer to sterile samples was recorded at both temperatures. At 60°C laundering with prewash produce a 6.9 LR with no transfer whilst laundering without prewash produced 3 LR with transfer of *S. aureus* to sterile samples.

Three studies of cross contamination of viruses during laundering are reported:

- **Sidwell and Dixon 1969**¹⁴ reported studies with cotton sheeting contaminated with polio and vaccinia virus laundered at 21-26°C. Using anionic detergent, the poliovirus was reduced by 2 log, and vaccinia by about 4 log to undetectable levels. Neither virus was detectable in the rinse water, but 1 log poliovirus was detected on sterile swatches included in the load. Using non ionic detergent, virus was reduced by >2 log although a significant quantity remained on the fabric. No virus was detected in the rinse water but both viruses were recoverable from sterile fabrics laundered with the inoculated samples.
- **Gerba and Kennedy 2007**²⁸ studied laundering at 20° to 23°C in removing adenovirus, rotavirus and hepatitis A virus from fabrics. The authors calculated that the wash and rinse cycle produced a 1.1-2.0 log reduction, but viruses were transferred to sterile laundry during washing to give contamination levels of 2.7-3.4 logs per 58 cm².
- **Heinzel et al. 2010**¹⁵ evaluated laundering at 30°C using heavy duty powder detergent against poliovirus inoculated onto cotton swatches. Where contaminated swatches were laundered in tap water only (poliovirus load 7.98 log/swatch) the average residual virus load on contaminated swatches after laundering was 5.3 log and levels of 4.0 log/swatch was found on sterile samples included in the wash. In contrast, when using the laundry detergent virus particles were inactivated to a level below the detection limit, i.e. >5 log reduction and no virus transfer to the sterile swatches was detected.

5.9 THE EFFECT OF DRYING

A number of studies show the extent to which drying can decrease the microbial load on fabrics. Studies where drying was carried out under conditions reflecting those used in the domestic situation are summarised in Table 5. The data suggest that, if contaminants are still present after laundering, drying, most particularly at higher temperatures can produce further reductions, although the extent of this reduction varied significantly from one study to another. Studies such as those of Blaser *et al.* 1984⁷, Patel *et al.* 2006²² and Eckert *et al.*⁴¹ show that ironing can significantly reduce microbial counts.

Reductions in microbial contamination will also occur where clothes are stored dry, but data in the 2011 IFH report¹, indicates that potentially harmful species such as *S. aureus*, *C difficile*, norovirus etc. can survive long periods (days to weeks or months) in the

absence of moisture. Fungi are particularly resistant to drying. This is a particular concern in relation to athlete's foot caused by *T. rubrum*, although no data could be identified on survival rates for this organism on dry socks or other clothing after laundering. For viral species which have been studied, survival on fabrics appears significantly less than bacteria, and survival on fabrics was significantly less than on non porous contact surfaces. Survival of viruses on fabrics was mostly around 30 min-12 h, up to a maximum of 48 h although some studies report longer times. Survival for fungal species ranged from 1 day to several weeks.

6. EPIDEMIOLOGICAL STUDIES ON THE EFFECTIVENESS OF LAUNDERING

Although, in an ideal world, it should be possible to determine whether reducing domestic laundering temperatures has any impact on infection rates, by carrying out an intervention study comparing infection rates in households where 60°C or 40°C laundering is consistently used with households where laundering is done at 30°C, such studies would be very difficult and costly to perform. Also, because of the interdependence of the pathways for infection transmission in the home, and the difficulties of controlling variables, it is doubtful whether such a study would yield valid results. However some evidence indicating that increased infection rates are associated with use of laundry processes which are less effective in reducing contamination levels during laundering (e.g. not using bleach during laundering) or increase the risk of pathogen transfer (such as using a communal laundry) comes from epidemiological studies carried out by Professor Elaine Larson and co workers.

In a study carried out between October 2000 and February 2003, Larson, Lin *et al.*⁴² evaluated the impact of cleaning and hygiene practices on the incidence of infectious disease in 238 households. Households were contacted by telephone weekly and visited monthly, and every 3 months an extensive home interview was conducted. Each household consisted of at least 3 people, including one pre-school child. The same households were also used in another study by Larson and Gomez-Duarte.⁴³ In both studies the infections investigated were non-specific and included fever, cough, cold, diarrhoea, vomiting, sore throat, skin infection or other infection. Hygiene practices studied were mostly non-targeted practices such as daily personal bathing or showering, laundry practices, bathrooms and toilet cleaning, changing of dish-sponges, or use/non use of antimicrobial cleaning products.

In the study of Larson, Lin *et al.*⁴², at the initial home visit and at the quarterly visits data were again collected regarding home hygiene practices (including laundry) and the self reported presence of new infectious disease symptoms during the previous month for each household member. At the baseline interviews, most households owned a washing machine (65.5%) and used bleach (i.e chlorine bleach) in the laundry (81.9%). At the baseline interview the use of bleach for laundry was significantly protective against infection. Participants were asked not to use bleach for the remainder of the study period. From the range of hygiene practices related to food handling, laundry, general cleaning and personal hygiene, drinking only bottled water was associated with increased risk (relative risk (RR) 2.1) whilst using hot water and use of bleach for laundering was found to be protective (RR 0.7 and 0.29 respectively). Reporting that germs were most likely to be picked up in the kitchen (i.e. displaying some evidence of good understanding of hygiene) was also protective (RR 0.5) but no other hygiene practices, including handwashing were found to be associated with infection risk. Unfortunately no information was collected on whether households separated higher risk laundry items (e.g. from the ill member of the household) from the rest of the laundry basket, and if so, whether they washed these items at a higher temperature (E.L. Larson, Columbia University, New York, pers comm. 2011)



In the study of Larson and Gomez Duarte,⁴³ 398 households were studied including 1,662 household members. From the range of hygiene practices studied, related to kitchen, laundry, general cleaning and personal hygiene habits, only 2 specific “targeted” practices, using a communal laundry ($p=0.009$) and not using bleach in communal laundering ($p=0.04$), were predictive of increased risk of infection. For the remaining practices there was no evidence of an association with infection risk.

In their discussion, Larson, Lin *et al.* question why, if bleach and hot water have an important protective effect, this association has not been reported previously. They suggest that the evolution from hot water to lower temp laundering has occurred very slowly over recent decades and may have been masked by other trends. Also because studies of laundry have been very infrequent over the past two, three decades.

7. USING QUANTITATIVE MICROBIAL RISK ASSESSMENT TO EVALUATE EFFECTIVENESS OF LAUNDERING

Whereas, on one hand, intervention studies yield quantitative data on health impact, but are costly and the reliability of estimates is difficult to confirm, on the other hand, *in vivo* and *in vitro* tests, although they can quantify the impact of hygiene procedures on transmission of infectious agents, give no assessment of how contamination reduction (LR values) correlate with health impact. Risk modelling is a promising approach, which is increasingly being applied to assess the impact of public health measures in reducing population infection rates, such as water interventions, hand hygiene etc., although it is recognised that it has limitations because of the multifactorial nature of infection transmission and the paucity of data to specify model parameters. Further information and data about the application and limitations of QMRA approaches can be found on the QMRA Wikipedia site (QMRAwiki) at:

http://wiki.camra.msu.edu/index.php?title=Table_of_Recommended_Best-Fit_Parameters.

Haas *et al.* have applied techniques of Quantitative Microbial Risk Assessment (QMRA) to estimate the relative health benefits resulting from the use of hygiene procedures such as hand hygiene and laundry hygiene with different efficacies.⁴⁴ This involves using microbiological data from the published literature, related to each stage of the infection transmission cycle to calculate infection risk. The following example illustrates that, whereas a quantifiable decrease in the log reduction (e.g. from 3LR to 0.95 LR) in contamination during laundering, may be discounted as insignificant in terms of an individual person, it can translate into a significant increase in the risk of infection transmission within a national population of 60-100 million.

Gibson *et al.*⁴⁵ used QMRA to estimate increased infection risks associated with laundering under conditions where the LR value is reduced. The study modelled transfer of *Shigella* (causes dysentery) from hand-to-mouth following hand contact with soiled compared with laundered clothing. To perform the risk assessment, a literature search was performed to obtain quantitative data on density of pathogens on clothing, the LR produced by laundering, transfer from laundered clothing to hand-to-mouth, and infectivity of ingested pathogens. After screening for quality, the data were used to develop probability distributions.

Based on an estimate that a person with symptomatic *Shigella* infection sheds from 10^5 to 10^9 cfu per gram of faeces (for asymptomatic infection, the average number is typically between 10^2 and 10^6 cfu/g), and taking the worst case situation (a person shedding 10^9 cfu per gram of faeces), Gibson *et al.* calculated that:



- Of 100 to 500 grams of faeces excreted per day approximately 0.1 g of faecal material remains on the undergarment (equivalent to 10^4 cfu per laundry item)
- Based on a laundry load of 3178g and a 54.5g piece of underwear (surface area of 1503 cm^2), once in the laundry, the bacteria are diluted and spread throughout all the clothing. Given normal laundering, producing 88.9% reduction, the number of cfu/sq cm clothing after laundering would be up to 1.2×10^2
- Based on previous studies by Gibson and co-workers which estimate an average of 50% transfer from fabric to hands by handling of washed laundry, the contamination level on the hands can be calculated as up to 6.3×10^1 cfu
- Assuming 10% transfer from hand to mouth by touching the hands to the lips, the probability of infection based on a dose response model is 3.1×10^{-5}

From this, estimates of the risk of acquiring shigellosis through contact with contaminated clothing before laundering was as high as 10 per million population to much lower levels associated with lower excretion rates of the bacteria in the faeces. These workers then compared the risk reduction associated with handling of the laundry after laundering under conditions which produced 88.9% (0.95LR) and 99.9% (3LR). From this it was calculated that whereas a 0.95 LR during laundering would produce approximately 90% reduction in probability of disease, by using a process which delivered a 3 LR during laundering the reduction in probability of disease could be increased to 99%. It should be kept in mind that this risk estimate does not take into account multiple exposures.

8. EVALUATION OF THE COMBINED EFFECTS OF DIFFERENT CONDITIONS (TEMPERATURE, DETACHMENT AND DILUTION, DETERGENT FORMULATION) ON EFFECTIVENESS OF LAUNDERING

In section 5, data from studies in which the effects of temperature, detachment and dilution, detergent formulation, organic load etc. were independently and systematically evaluated is presented. Although evaluation is made difficult by the interdependence of these factors (e.g detachment and dilution effects are increased by inclusion of detergent, which in turn increases with temperature), overall the evidence consistently shows that:

- 3 key factors, temperature, detachment and dilution laundry product formulation all make a significant contribution to the overall effectiveness of laundering,
- changes in any one of these factors substantially affects effectiveness of laundering.

In the following section, an attempt is made to use the combined data from all studies to draw conclusions about the extent of the impact of reducing laundering temperatures to 40°C and 30°C , and its significance in relation to the impact of other factors (detergent formulation, dilution, etc.) which contribute to the effectiveness of laundering. In order to compare data from different studies, data from sections 5.1 to 5.9 are summarised in Tables 1-5 which show key parameters and LR values obtained from each study.

A key finding, illustrated by Tables 1-5, is the variability between LR values obtained at any given temperature, which makes it difficult to be confident about conclusions involving the combined data. This variability is hardly surprising. Methodological details indicate a number of factors which varied significantly from study to study each of which may have had a significant impact on the LR values obtained:

- Although standardised methods were used for preparing contaminated fabrics, enumerating contamination etc., variability in the extent to which samples were dried before laundering may have a significant effect on ease of detachment
- Whereas in some studies, temperature was carefully controlled, in others it was not. It is possible that in some cases the required temperature was not reached and it is

- likely that there would have been a significant but variable temperature drop during washing
- Effectiveness is likely to be influenced by laundering conditions such as the fabric type, machine design and operation (water volume, cycle time, agitation during wash cycle, number of rinses) and formulation and dosage of the detergent which varied considerably from one study to another.
 - The majority of studies were performed in the presence of “high load” soiling, which is not necessarily relevant to “daily wear” clothing which may be contaminated with organisms from the skin and faecal flora but may have relatively modest levels of soil (blood, faeces, skin scales, body secretions, food material etc.) relative to those found on fabrics in risk situations. The types and amounts of soil however varied significantly between studies.
 - Many of the studies are aimed at addressing specific issues rather than understanding in a “dose:response” manner, the effects of temperature, rinsing, powder formulation, organic soiling etc. In some cases the limit of sensitivity of the assay is exceeded such that LR values are recorded as “greater than” and the effects of individual variables are not thus distinguishable.

Since no systematic studies were performed, there is no indication as to what extent these factors might have contributed to LR values obtained and the variability of the results.

The lack of standardisation and the resultant variability in LR values also means it is not scientifically valid to determine “mean values” from the combined data. To further evaluate the combined data, identify possible trends (dose:response relationships) and establish what LR values might reasonably be expected under a given set of laundering conditions, the approach which has been used in the following sections is to summarise, LR values from Tables 1, 2 and 3 into Tables 6- 9 which show the range (minimum, median and maximum) of LR values. These min-med-max profile of LR values were then used for a given set of laundering conditions to draw conclusions.

This method of data handling has involved some measure of expert judgement and data manipulation which could be regarded as heuristic rather than rigorous. Because of this and because of the lack of standardisation of other test conditions, and, for some conditions the paucity of data points, the data in these tables needs to be regarded with caution. This method of expressing the results however allows us to do a number of things:

- identify whether “dose response” trends identified in section 5 are common to the combined data
- compare min, max and median profiles of LR values for different laundering conditions on a semi quantitative basis
- identify what additional data points are required to give more confidence in the results
- Identifying outliers allows us to look for methodological variations which might account for the high or low value obtained
- inform decisions about what future studies are needed to give clearer insights and greater rigour to the results.

8.1 THE IMPACT OF TEMPERATURE, DILUTION AND DETERGENT FORMULATION ON THE HYGIENE EFFECTIVENESS OF LAUNDERING

In the following sections observations about the combined effects of temperature, detachment and dilution, and detergent formulation are discussed.



8.1.1 The impact of temperature

A major objective of this report is to assess, based on currently available data, whether, and to what extent, effectiveness of domestic machine laundering might be compromised by laundering at temperatures of 30°C or 40°C, rather than 60°C.

Sections 5.2 to 5.5 collated studies involving bacteria, viruses and fungi. In order to compare data from different studies. These data are summarised in Tables 2 and 3. For the most part studies were carried using strains representative of infectious species likely to be found on contaminated fabrics in the domestic home. Where studies involved more than one bacterial test organism, data generated using *S. aureus*, *E. faecalis* and *E. faecium* as test organisms, which are regarded as typically more resistant to heat, are shown in the Table 2.

To get an overview, from the combined data, the minimum, median and maximum range of LR values for each laundry temperature, for fabrics laundered with non AOB detergent which are summarised in Table 6 using the data from Table 2. It was decided to omit the LR Values of 1.3, 1.4, 4.5 and 4.8 obtained by Fijan *et al.*³⁴ for the 60°C cycle, because they represent LR during the wash cycle only (i.e samples were taken at the end of the cycle, before rinsing). A possible reason for the relatively higher LR values obtained by Lakdawala at 30 and 40°C is the inclusion of BSA in the bacterial test suspension which may have resulted in a lower organic loading relative to other studies where e.g defibrinated sheeps blood was added to the wash load. The data also suggest that *E. faecium* (possibly also Acinetobacter) may be more resistant than *E. faecalis* and *S. aureus*.

Overall the weight of evidence, as summarised in Table 6 confirms the conclusions set out in section 5.3, that effectiveness of laundering decreases significantly with decreasing laundry temperature. Results suggest that the greatest loss of effectiveness occurs between 60 and 40°C, but more systematic data is needed to confirm this. Results suggest some further reduction in effectiveness between 40 and 30°C, but little or no further reduction between 30°C down to 15°C. From their study of European laundering processes, Terpstra *et al.* 2003¹² made some statistical estimates. Although they found that that the hygienic quality was significantly better after laundering at 60°C than at 40°C, unfortunately, in all countries, laundering at 60°C was done with an AOB-based product, whilst for all but one 40°C study, non-AOB detergent was used. They stated that there was “a significant temperature effect on hygiene quality between the 40 and 15°C programmes (ANOVA-one way, $\alpha=0.05$)”, but their study design did not allow for any conclusions to be drawn about difference in effectiveness between 40°C and 30°C.

For viruses, although the data are relatively limited, the min-med-max profiles for the combined data, as shown in Table 7, confirms that effectiveness of laundering against viruses is reduced at lower temperatures. The total data in Table 7 again shows that there are considerable inconsistencies between LR values from different studies. Excluding the data of Heinzl (where an AOB detergent was used) the data suggests a median LR value of 3.7 at laundering temperatures of 54-60°C compared with a median value of around 2 at cold wash temperatures of 21-27°C. Unfortunately there is no data available for 30°C but the data suggests that the effectiveness at 21-27 and 35-46°C is of the same order as against bacterial strains at similar temperatures.

The data of Block *et al.* 2001³⁷, Fijan *et al.* 2007³⁸, Ossowski and Duchmann 1997³⁹, 1999³⁶ and Hammer *et al.* 2011³⁵ confirm that effectiveness in elimination of fungal species such as *T. Rubrum* and *C albicans* also decreases as the temperature

decreases, although the number of data points was insufficient to support collation of min-med-max profiles.

Looking at the combined data range of LR values for the bacterial strains in Table 6 (which provides the greatest number of data points) suggests that a 5 log reduction could be achievable at 30°C (data of Ainsworth *et al.* 1989¹⁰, 1993¹¹ and Lakdawala 2011¹³), whilst LR values of 4-5 might be achievable at 40°C (data of Terpstra *et al.* 2003¹² and Lakdawala *et al.* 2011¹³). Whilst further investigation is required to determine why these high end LR values were obtained and whether and how the wash cycle might be manipulated to consistently achieve these values, it suggests the possibility to achieve values of 4 and 5 log reduction at these temperatures. It would be important however to ensure that these LR values are sustained across the range of fungal and viral species as well as bacteria.

8.1.2 The impact of detachment and dilution

To assess the contribution of detachment and dilution to reducing contamination on fabrics during laundering, the range, minimum, median and maximum LR values from 11 studies where laundering was performed without detergent, or laundering with and without detergent were compared, are summarised in Table 8 using data from Table 1. Only data obtained at 40°C or less was included where it is unlikely that there is significant lethal action of heat.

The variability of these data is not unsurprising since conditions which determine the impact of detachment and dilution, including detergent formulation, volume of wash and rinse water, extent and duration of agitation during wash cycles and number of rinses, varied significantly from one study to another. Terpstra *et al.*¹² estimated that the LR value due to adding an additional rinse cycle is of the order of 1 log. Another factor likely to affect detachment is the extent to which contaminated fabrics were dried before laundering; studies reviewed in the IFH 2011 report¹ show that strength of adhesion to fabrics increases with drying.

The low LR values obtained by Jaska and Fredell at 27°C (0.38-0.7) may relate to the fact that rinse and drain rather than rinse and spin cycles were used. However the very low value of <1 recorded by Linke *et al.* 2011²³ for laundering with non-AOB detergent at 30°C is difficult to explain. The highest values were obtained by Sidwell *et al.*¹⁴ which indicated LR values up to 5.6 (using poliovirus as test strain) in the presence of detergent at 27°C, and by Lakdawala *et al.*¹³ which indicated LRs of 3.4 and 4.9 (using *S. aureus* and *A. baumannii* as test strains) for laundering in the absence of detergent at 38-40°C. The data of Lakdawala *et al.*¹³ is also somewhat surprising. For *A. baumannii*, the data suggest that the LR at 30 and 40°C (2.1 to 3.6) is equivalent to that produced by water detachment and rinsing alone.

It is reasonable to expect that the impact of detergency is enhanced at higher temperatures, although from the data of Sidwell *et al.* 1971²⁷, Jaska and Fredell 1980⁹ and Davis and Ainsworth 1989¹⁰, where laundering with and without detergents at temperatures of 50 and 60°C were compared, only the data of Davis and Ainsworth confirm this.

In section 5.1 it was calculated that, if there was 100% detachment of microbes from fabrics during laundering, the dilution factor for a machine wash and 2 rinse cycles could be as high as 4 logs. The LR values obtained thus suggest that, for fabrics which are heavily contaminated, a significant proportion of the contamination remains on fabrics after washing and rinsing at low temperatures. Overall the combined data from this review suggests that values of 2LR or more are obtained during laundering due to

detachment and dilution alone (i.e. without any contribution from inactivation due to temperature or to constituents of the detergent. The data suggests that LR values due to detachment and dilution could be enhanced by improvements in washing machine design and operation or detergent formulation, in order to increase the effectiveness of laundering at lower temperatures.

8.1.3 The impact of detergent formulation

Data in section 5.3 confirms that LR values during laundering can be significantly enhanced by including TAED/perborate or percarbonate components in the detergent which release active oxygen and inactivate microbes which remain attached to fabrics. In all we identified 6 systematic studies (Linke *et al.* 2012²³, Bellante *et al.* 2011²⁴, Lichtenburg *et al.* 2006²¹, Terpstra *et al.* 2003¹², Vossebein 2013²⁹, Lucassen and Bockmuhl 2013³⁰) indicating that effectiveness of laundering is significantly increased by inclusion of AOB in the detergent.

To get an overview, min-med-max LR values from Table 6 for laundering at 60°C, 38-40°C and 30-31°C with non AOB detergent were compared with those for fabrics laundered with AOB detergent at equivalent temperatures. The combined data are shown in Table 9. For AOB detergents, data from Block *et al.* 2001³⁷ and Patel *et al.* 2006²² is also included:

- For **laundry cycles at 60°C** and above, Linke *et al.* 2011²³ showed that effectiveness could be increased from 4.22 to >8 LR using AOB detergent, compared with a non AOB liquid detergent. Studies by Vossebein 2013²⁹ and Lucassen and Bockmuhl³⁰ also indicated that the LR at 60°C was increased by use of an AOB compared with non AOB detergent. Although Bellante *et al.*²⁴ and Lichtenburg *et al.*²¹ carried out studies at 60°C, no meaningful comparisons could be made because there was no detectable residual contamination after laundering for both AOB and non AOB studies.
- For **laundry cycles at 40°C**, Linke *et al.* 2011²³ showed that LR increased from <1 up to 8 by using AOB detergent compared with non AOB detergent. Similarly Lichtenburg *et al.* 2006²¹ showed that LR values increased from 2-2.5 up to >3 (no detectable survivors) using an AOB, compared with non AOB detergent. At 40°C Bellante *et al.* 2012²⁴ found that, after laundering fabrics contaminated with lactobacilli-containing yoghurt using AOB detergent, no lactobacilli were detected, compared with laundering with non-AOB detergent where small numbers of lactobacilli (0-8 per contact plate) were found. Lucassen and Bockmuhl³⁰ found that LR was increased by using an AOB detergent. Studies by Vossbein 2013²⁹ showed no significant increase.
- Even for **laundering at 30°C**, use of an AOB detergent appears to produce an increase in effectiveness of laundering by 1-2 log or more. For laundry cycles at 30°C, Linke *et al.* 2011²³ showed that the LR using an AOB detergent was 3.0, but <1 using a non AOB liquid detergent. Lichtenburg *et al.* 2006²¹ showed that, at 30°C, AOB detergent produced a >3 LR (i.e no detectable survivors), whilst non AOB detergent produced only 0.5 to 1.2 LR. Bellante *et al.*²⁴ found that, after laundering with an AOB product at 30°C, no lactobacilli were detected, but, after laundering with non AOB detergent, lactobacilli (128-2000 per contact plate) were isolated. By contrast Lucassen and Bockmuhl³⁰ found that the LR was greater (50% reduction) following use of a non AOB detergent as compared with an AOB detergent (17% reduction).

Although there are insufficient data points for the AOB detergent to be confident, the data suggests that, by including AOB in the detergent, it is possible to achieve the same profile of hygiene effectiveness at 30°C (min, median and max LR = 1.9, 3.0 or more, 7.2), as at 40°C (min, median and max LR = 2.0, 3.0, >7) using a non AOB detergent.

In conclusions from their studies with a range of AOB and non AOB detergents at different temperatures, Terpstra *et al.* 2003¹² concluded “a significant effect of using an AOB on the hygienic quality of laundry is found (ANOVA-One Way, $\alpha = 0.05$). The hygienic quality improves when detergents with bleaching agents are used. This was also confirmed by an additional test at 60°C without bleaching agents” (although results of these experiments are not stated). In contrast to Linke *et al.*²³ and Lichtenburg *et al.*²¹, results taken from the report of Terpstra *et al.* 2003¹² (tabulated in the appendix of this review) suggest that, use of AOB detergent had no impact at 30°C or less. Terpstra *et al.* 2003¹² studied total counts and enterobacteria counts on naturally contaminated diapers, cloths, handkerchiefs and socks. In 2 of 4 trials an AOB powder was used whilst in the other 2 trials non AOB powder was used. Results indicated that there was no apparent difference between LRs (or the extent of cross contamination to sterile fabrics) obtained by laundering with AOB compared with non AOB detergent at either 15°C or 30°C.

The data of Heinzl *et al.* 2010¹⁵ suggests that laundering with AOB detergent can also enhance effectiveness against viruses.

It must be borne in mind that the surfactant components of laundry detergents can themselves exert some microbicidal effect which is thought to be greater against Gram positive than Gram negative species,⁴⁶ but there are no published data indicating the extent to which this action might contribute to hygiene effectiveness of laundering. It is likely also that this effect may be enhanced as temperature increases. Unpublished data (Bloomfield, pers comm.) where efficacy was determined using suspension tests suggest that the contribution may be quite significant (up to 1 log or more) but this requires further investigation.

8.2 IMPACT OF SOILING

An aspect which requires further consideration is the impact of soiling. For effective laundering of items where heavy soiling may be expected e.g items contaminated with blood vomit or faeces, it is entirely appropriate to expect adequate performance in the presence of “high load” soiling. As discussed in section 5.7, for almost all studies in this report, what are considered in hospital situations to represent high levels of soil (mostly in the form of defibrinated blood or serum albumin) were added to machine wash loads. It is likely that the soil levels selected for these tests are based on specifications in standard EPA and DGHM tests methods, which in turn are based on soil levels historically used for testing of hospital disinfectants used for treatment of surfaces contaminated with blood and body fluids.

We could identify no studies in which the impact of soiling was studied in any systematic way, or which attempted to match test soil levels to those likely to be found on “normal” day to day clothing etc. Whilst the levels of soil used in the studies reported here may be appropriate for “higher risk” domestic laundry items which may be heavily soiled with potentially infectious material e.g vomit, faeces, by contrast, for normal day to day clothing and linens, even those which come into significant contact with the body, it may be unnecessary to require laundering conditions to comply with tests in which high soil levels are included in the test mixture. These lower risk items may be contaminated with skin and faecal organisms, but have relatively low load soiling. It is interesting to note that the data produced by Terpstra *et al.* 2003¹² was generated using soiled clothing, but additional soiling (defibrinated blood) was added to all wash cycles.

In setting performance requirements for fabric items for which may not be heavily soiled, there is a need for more data on the likely soil loads on these items and on the relative impact of high and low protecting loads on the effectiveness of laundering.



8.3 IMPACT OF DRYING

Studies, as reviewed in section 5.9, show that, after laundering, the number of residual survivors on fabrics can be further reduced by drying and ironing. Although drying at elevated temperatures can produce 1 or more LR in contamination levels, using tumble drying as a means to compensate for reductions in hygiene effectiveness of laundering at lower temperatures would be counterproductive in terms of energy conservation.

Other components of the laundering process such as drying in sunlight (which has a microbicidal effect due to UV light) and ironing (particularly steam ironing or ironing damp) also contribute to reducing the microbial load.^{22,47} However practices vary considerably from family to family and from day to day, according to climate, nature of the fabrics, lifestyle etc. The practice of ironing is now less common in many households with the use of wrinkle-resistant fabrics. A 2012 UK market research report⁴⁸ stated that "Ironing is most likely to be done just once a week, with 32% of adults making ironing a weekly household chore, while 27% of people tackle the job less than once a week or not at all". Although all of these factors have the potential to contribute to laundry hygiene, it is impractical to take them into account, because of the inconsistency of drying and ironing habits and the counterproductive nature of heat drying.

8.4 CONTROLLING KEY PARAMETERS DURING DOMESTIC LAUNDERING

Evaluation of the methodological details indicates a number of factors which varied significantly from study to study which may have contributed to the variability in the LR values obtained. Although there was insufficient data given for many studies, variations in machine design, and machine operation in terms of the wash cycle time, agitation during the wash cycle, number of rinses and volume of rinse water are likely to have been significant sources of this variability. Data, where recorded, on these parameters is summarised in Table 10. Data recorded by Bellante *et al.*²⁴ illustrates how laundry processing in private homes is subject to enormous fluctuations. Data for typical domestic machine wash cycles operated at 20-60°C as carried out in different machines 32 different households in Germany, the cycle time could vary from around 15 to 120 min, Importantly, there was no correlation between wash time and temperature (i.e lower was temps did not typical correlate with longer wash times).

A particular factor which is likely to have a significant impact is temperature control. Whereas in studies such as that of Lakdawala¹³, the temperature was carefully controlled and maintained throughout the wash cycle, in most others it was not and it is likely that there would have been a significant temperature drop during washing. This is illustrated in 2 recent studies which suggest that in many cases the machine contents fail to reach the specified temperature:

In a 2013 study reported by Vossebein²⁹, textiles contaminated with yoghurt containing lactobacilli were washed in a domestic washing machine set at 40 and 60°C During the cycle, loggers were used to monitor the temperature profile of the washing programme:

For the 3 programmes set at 40°C

- 40°C reached quickly: around 37°C was maintained for about 15 minutes.
- 40°C was not reached; around 35°C was maintained for about 20 minutes.
- 40°C was not reached; around 37°C was maintained for about 30 minutes

For the programmes set at 60°C



- Highest temperature about 53°C; over 20 min wash cycle, temp decreased to 46°C
- Highest temperature about 46°C; over 20 min cycle, around 43°C was maintained.
- Highest temperature about 53°C; over 25 min cycle, temp decreased to 50°C.

The results showed that, even within what are assumed to be the same washing programmes and detergents, there was considerable fluctuation in the microbiological quality of the washed fabrics. The authors concluded that “Even using supposedly safe hygiene programmes such as 60°C and the use of an all-purpose detergent containing AOB did not provide satisfactory results with regard to hygiene”.

In another study, Lucassen *et al.* 2013³⁰ evaluated laundering of cotton guest towels which had been used regularly for three consecutive days in the sanitary facilities of the Rhine-Waal University of Applied Sciences. Towels were washed in a domestic washing machine at 30°C, 40°C and 60°C. The exact temperature profile of the laundry program was monitored using a UHF temperature sensor-transponder. Monitoring the temperature profile during the wash cycle, showed that:

- For the programme set at 60°C, the maxim temperature was 50°C which declined to around 46°C during the 20 min holding period
- For the programme set at 40°C, the maximum temperature was around 38-39°C which declined to around 37°C during the 20 min holding period
- For the programme set at 30°C, the maxim temperature was around 28-29°C which was largely sustained during the 55 min holding period

A 2013 WHICH report showed that around two thirds of UK domestic washing machines set to 60°C did not actually reach the prescribed temperature⁴⁹

9. THE IMPACT OF LAUNDERING IN REDUCING INFECTION RISKS ASSOCIATED WITH CLOTHING AND HOUSEHOLD LINENS

Overall the data in this review indicates that reducing laundry temperatures can result in a significant increase in the numbers of bacteria, viruses and fungi which survive the laundering process. The important question is whether this is accompanied by an increase in risk of spread of infection which is significant in public health terms, or whether the increased risk is negligible, compared say with hands and high frequency contact surfaces, and can be ignored.

Whilst laundry hygiene is important, equally it is important to consider sustainability issues i.e. the environmental impact of higher temperature laundering, use of detergents and other chemicals, and the need to conserve water. In recent years the household soap and detergents industry has made a significant investment in developing laundry products that perform (i.e. deliver clean clothing) at low temperatures. The energy consumption required to heat the water in a washing machine contributes by far the largest proportion of the environmental impact of laundering. In order to save energy, increasingly over the past few years, home laundering has been carried out at lower temperatures (30-40°C).

9.1 INFECTION RISKS ASSOCIATED CLOTHING, HOUSEHOLD LINENS AND OTHER FABRIC ITEMS

The extent of the infection risks associated with home hygiene practices such as laundering, handwashing, surface hygiene etc. is difficult to assess using standard epidemiologic methods. The most direct method would be to compare infections rates in homes where laundering is carried out regularly or rarely (or at different temperatures), but the difficulties of controlling variables and determining with any confidence whether increased infection rates are due to laundering habits as opposed to other interrelated



routes of transmission mean that this is not a viable option. Most cases of illness in the home are not reported, and, where they are, the exposure route is rarely identified. Thus, alternative approaches are needed.

In formulating home hygiene practice advice for consumers, IFH has adopted a risk-based approach, known as targeted hygiene, to develop evidence-based risk reduction strategies. This is based on well-accepted Risk Management approaches used in food and other manufacturing industries, and healthcare settings for quantifying risks associated with hazardous microorganisms and developing an effective multibarrier approach to preventing the spread of these organisms. The first step is *hazard identification* where pathogens likely to be associated with infection are identified. The next step is *dose-response assessment* where the probability of infection given exposure to a particular dose of pathogens is assessed. The third is human *exposure assessment*, which describes the likely intensity, frequency, and duration of exposure, as well as exposure routes and immune status of persons exposed. Finally, *risk characterization* integrates the results from hazard identification, exposure assessment, and dose-response to arrive at an assessment of overall risk to the population.

In 2011 IFH carried out a detailed analysis of relevant microbiological and epidemiological data, and used it, as part of a risk management approach, to assess potential risks from exposure to infectious disease agents transmitted via clothing etc. relative to hands and other surfaces in the home.¹ It was concluded, as a consensus view by the IFH Scientific Advisory Board, that clothing and household linens etc. can be a risk factor for transmission of infection in home and everyday life settings during normal daily activities which needs to be properly assessed and managed through effective hygiene practices as part of a multibarrier approach. These conclusions were drawn from analysis of data showing how pathogens, or strains which may spread antibiotic resistance determinants are transferred to clothing etc. from a variety of sources during normal daily life, and the extent to which they can survive and spread from contaminated fabrics to hands and surfaces, such that we can become exposed to potentially infectious doses. The review also identified some 18 observational studies of cases, outbreaks of infection and self-reported infections in which clothing, etc. was identified as a likely source of infection transmission. Importantly the report concluded that, although it is likely that clothing etc. can act as a vehicle for infection transmission, the “daily life risks” are probably somewhat less than those associated with hands, hand contact and food contact surfaces and cleaning cloths which are seen as the key routes of transmission.

Infectious agents that have potential for spread via clothing etc. include enteric bacteria such as *Salmonella*, *Shigella*, *Campylobacter*, *E. coli* (including *E. coli* O157 and O104) and *C. difficile*, and enteric viral strains such as norovirus, rotavirus, adenovirus and astrovirus. It also includes respiratory (cold and flu) viruses such as rhinovirus, influenza virus, respiratory syncytial virus etc. The risks from skin pathogens are mainly associated with *S.aureus* (including MRSA), yeasts (such as *Candida albicans*) together with dermatophyte fungal strains such as *T. mentagrophytes*, and viral strains such as herpes. As stated previously, in developed countries *T. rubrum* accounts for 70% of all dermatophytoses (including athlete’s foot) in humans and can be transmitted via socks. Domestic laundry items most likely to be contaminated with, and be a vehicle for spread of these pathogens, are those which come into direct contact with the body e.g. underwear, shirts, socks, personal towels, sheets, pillows, facecloths, nappies.

Although risk assessment gives an assessment of the “daily life” infection risks associated with household fabric items, it is important to recognise that these risks are not constant, and can increase significantly under certain conditions. e.g. in healthcare situations. In particular the evidence strongly indicates that clothing and household linens are a significant risk factor for spread of *S. aureus* (including MRSA and PVL-producing



MRSA strains), and that effectiveness of laundry processes may be an important factor in defining the rate of community spread of these strains.¹ Data in the 2011 IFH¹ report shows that the risk of transmission via clothing etc. is likely to increase in situations where a family member has diarrhoea or vomiting, or a skin or wound infection. It also increases in circumstances where a family member has reduced immunity to infection. People with reduced immunity now make up an increasing proportion of the population, currently up to 20%.⁵⁰ The largest proportion is the elderly, many of whom have chronic ill health with associated vulnerability to infection. In situations of increased risk the approach to hygiene is the same as for “normal” family members, the difference being that, if effective procedures are not used and/or these procedures are not rigorously applied there is higher infection risk.

As stated in the 2011 IFH report,¹ in addition to assessing risks of spread of infectious disease, another aspect needs to be considered. Tackling antibiotic resistance is now a global priority, and, in the last few years particularly, there has been increasing awareness that hygiene measures are an important part of reducing spread of resistant strains.⁵¹ Currently, the focus is on resistant superbugs in hospitals, but it is now recognised that this is just as much a home and community problem. In the community, otherwise healthy people can become persistent skin carriers of MRSA,^{52,53,54} or faecal carriers of enterobacteria strains which can carry multi-antibiotic resistance factors (e.g NDM-1 or ESBL-producing strains).^{55,56} Because these people are perfectly healthy, the risks are not apparent until, for example, they are admitted to hospital, when they can become “self infected” with their own resistant organisms following a surgical procedure, and then spread it to other patients. It is thought that the major source of nosocomial pathogens is the patient’s endogenous flora.⁵⁷ Sometimes these infections occur in the community, as happened in 2005 when a young soldier acquired what should have been an easily treatable skin infection from a PVL-producing strain of MRSA, but subsequently died.⁵⁸ As persistent nasal, skin or bowel carriage in the healthy population spreads “silently” across the world, the risks from resistant strains in both hospitals and the community increases. In the last few years a significant amount of new data has been published showing the extent to which “healthy” people can carry resistant strains, and how person to person transmission of these strains can occur within the home. Data on spread of resistant strains in the home and community is reviewed in more detail in a 2013 IFH document.⁵⁹

Whether, or to what extent underclothing might be a vehicle for spread of *C. difficile* in the community is not known. A study carried out in Oxford University Hospital NHS Trust area, between 2008 and 2011, suggests that only about 1 in 5 of *C.difficile* infections are being spread between patients in hospital.⁶⁰ There is growing awareness that community-acquired *C. difficile* is important and there are data indicating transmission to humans from animals. Studies suggest carriage rates for *C. difficile* in the healthy adult community of up to 3% with higher colonisation rates in the over 65 age group.^{61,62}

Data reviewed in the IFH 2011 report suggests there are a number of points where clothing and household linens can act as disseminators of potentially harmful or antibiotic resistant strains such that family members may be exposed and become colonised or infected. For example:

- During wear, or use of items such as underwear, socks, bedlinens, towels etc. which are contaminated with potentially harmful or antibiotic resistant strains
- When infected family members share items such as towels with other family members during normal daily activities
- When members of sports teams share items such as towels
- Where contaminated and non-contaminated items are included in the same laundry cycle, contamination can pass from contaminated to uncontaminated items



- When contaminated clothing is handled before laundering or when inadequately laundered items are transferred/handled from the washer
- If there is a build up of microbes in the washing machine (e.g build up of biofilms) these may be deposited on the clothing etc. during laundering
- If the laundry process fails to fully remove contamination and laundry remains damp for a period, there is the chance for growth of residual micro-organisms, such that clothes then become a more significant source of microbes.

Since there is no quantitative intervention study data assessing the impact of laundering on infection and/or colonisation rates, there is a tendency to assume that the risks are therefore minimal. This may be the case, but, equally, without data, it is impossible to conclude that it is not. Most certainly, risk assessment using microbiological data as set out in the 2011 IFH report suggests that infection risks from clothing etc. are less relative to other “control points” (hands, hand and food contact surfaces etc.). However, the data from Larson *et al.* as discussed in section 6 indicate that these risks should not be dismissed. Their study of New York households showed that, out of a wide range of hygiene practices studied, 2 specific “targeted” laundry practices, using a communal laundry and not using bleach in communal laundering, were predictive of increased infection risk, whereas for all other cleaning practices which were assessed there was no evidence of association with infection risk⁴³. In a further study⁴² they found that using hot water and using bleach for laundering was found to be protective against infection. Although the example used in the calculations of Gibson *et al.* (section 7) were associated with a specific highly pathogenic organism, Shigella, it demonstrates the principles, in a quantitative manner, of how inappropriate hygiene effectiveness of laundering in case of an enteric infection, could translate into a significant increase of the infection rates within a population. Although it must be noted that in absolute terms this risk is still relatively low compared to that associated with, for example, the hands.⁴⁵

The desire to wear and use clothing etc. which is clean, is deeply rooted part of our culture in terms of nurturing our families, feeling good about ourselves and so on. From a public health perspective, it is important that the process of laundering is effective not only in delivering visibly clean clothes, but also in managing risks associated with spread of potentially harmful microbes, bearing in mind that visibly and hygienically clean are not necessarily the same thing.

9.2 MANAGING INFECTION RISKS ASSOCIATED WITH LAUNDRY

In order to set minimum performance requirements for domestic laundry processes which are appropriate for managing infection risks, the following need to be taken into account:

- What levels (bioburdens) of potentially harmful and/or antibiotic resistant strains (e.g. meticillin resistant *S. aureus* or multidrug resistant faecal coliforms) are typically found on clothing etc. after wear or use
- What levels of residual contamination after laundering constitute an infection or colonisation risk, bearing in mind how the fabric will be handled, worn or used, and by whom.

Bioburdens of pathogens on domestic clothing etc. after wear or use

The literature contains a significant amount of evidence demonstrating that skin, intestinal and other body flora organisms (including pathogens where someone is infected or colonised) are shed from the human body into the environment and onto clothing, or from contaminated food onto surfaces and the cloths used to wipe them. By contrast however, there is relatively little data showing the extent (frequency or bioburden) to which these organisms are actually found on clothing and household



linens, cleaning cloths etc. after wear or use. The available data is reviewed in the 2011 IFH report¹ (section 3.2). It seems reasonable to conclude that performance requirements for laundering should be based on levels of pathogens or other organisms likely to be a hazard (e.g skin of intestinal species which may bear antibiotic resistance determinants) rather than total counts. Data suggest that total microbial bioburdens after wear or use, can range from 10^2 to 10^8 cfu/cm², but indications are that these are mostly non-pathogenic microbes including from the body flora or G+ve bacilli from the environment (Blaser *et al.* 1984⁷, Nicoles⁴⁰, Terpstra *et al.*¹²) which do not pose an infection risk (other than *C. difficile*). Since some of these organisms are particularly resistant to the lethal effects of heat, this suggests that total counts are inappropriate for testing effectiveness of laundering in managing infection risks.

Since random sampling of used or worn clothing and linen confirms that normal skin flora species such as staphylococci, micrococci, corynebacteria etc. are commonly found on these items^{63,64,65}, it is reasonable to assume that, for people who are infected or carriers of *S. aureus* (estimated between 30 and 60% of the general population⁶⁶), these organisms would also be found on their clothing etc. It is known that people who carry *S. aureus* can shed the organism in large numbers during normal daily activities, most usually associated with skin scales. It is estimated that around 10^6 skin squames containing viable organisms are shed daily from normal skin.⁶⁷

In a US study⁶⁵ samples taken from cotton towels in public places (public washrooms, restaurants, airports, bus or rail stations) yielded *S. epidermidis* (23% of samples), *Corynebacteria* (19%) and *Micrococci* (13%) but *S. aureus* was also isolated on two samples. In their study of bathroom towels in 200 UK homes (Scott and Bloomfield 1982)⁶⁸ frequency of isolation of *S. aureus* was 3.6%. Scott *et al.* sampled a total of 32 surfaces in kitchens, bathrooms, and living areas In a study of 35 homes of healthcare and non-healthcare workers in Boston USA, each with a child in diapers and either a cat or dog in the home, MRSA was isolated from 9/35 homes and was found on 3% of sponges or counter wiping cloths and 7% of dishtowels.⁶⁹ In homes where there is an MRSA carrier, MRSA was isolated from laundered items (personal communication from Martin Exner, May 2001).

The potential for contamination of clothing etc. with enteric bacteria and viruses was reviewed by Gerba and co-workers.^{28,31,45} Based on estimates that 0.01-10g of faecal material may be found on an undergarment after wear, and that the reported concentration of enteric viruses such as adenovirus, rotavirus and hepatitis A virus in faeces of infected individuals may be as high as 10^{10} to 10^{11} /g, they calculated that significant concentrations could be present on undergarments before laundering, even though garments may not appear soiled. It is estimated that a single vomiting incident following norovirus infection may produce 30 million viral particles.⁷⁰ Based on an estimate that a person with asymptomatic *Shigella* infection sheds between 10^2 and 10^6 cfu/g, Gibson *et al.* calculated that, if approximately 0.1 g of faecal material remains on an undergarment, this is equivalent to between 3.1×10^{-3} and 3×10^1 cfu/g of laundry item.⁴⁵ In their study of bathroom towels in 200 UK homes (Scott and Bloomfield 1982)⁷¹, the frequency of isolation of *E. coli* was 2.6% and 0.5% for *P. aeruginosa*. In a study of 15 US homes sampled over 30 weeks, the mean count of faecal coliforms per ml of rinse fluid from sponges or dishcloths was 10^5 .⁷² Blaser *et al.* found that 52 of 345 different bacterial isolates from soiled hospital sheets and terry cloths were *E. coli*.⁷

Some limited data on bioburdens of potentially harmful species comes from studies in Japan. Ojima *et al.* (2002)⁷³ found that, where *E. coli*, *P. aeruginosa* and *S. aureus* (and also coliforms) were found on kitchen, hand and counter towels, and bathroom and toilet handtowels, counts were mostly between 1 and 9 cfu/10 cm², but counts of 10-1000 were sometimes recorded. In another study, coliform bacteria (mean levels 10^2 - 10^4 /cm²) and

E. coli (1.5×10^1 in underwear up to 10^5 in cloths) was found. As discussed below, Terpstra *et al.* 2003¹² consistently found counts of Enterobacteriaceae of the order of 7-9 log and 6-8 log per 4.7 cm^2 respectively on diapers and cloths after wear or use.¹ Although *S.aureus* was detected, no data is given for initial counts. By contrast handkerchiefs and socks were only occasionally contaminated with Enterobacteria, and, where detected counts were not more than 1 log per 4.7 cm^2 .

These data suggest that, for laundry effectiveness studies reported in this review, test inocula on fabric samples were appropriate to represent heavily contaminated items such as diapers and cleaning cloths after wear or use, (although for some studies inocula were as high as 8-9 log). However much more data is needed on the maximum bioburdens of strains such as *S. aureus*, faecal (entero) bacteria, enteric and respiratory viruses, and fungi likely to be found on different types of clothing and household linens etc., both under normal daily life conditions and under conditions e.g. where there is an infected person or a carrier/shedder of *S.aureus*.

Exposure risks from residual contamination after laundering

Only a very small number of studies have evaluated levels of potentially harmful organisms on clothing etc. after laundering. In the studies of Terpstra *et al.* 2003¹² where, before laundering, enterobacteria were detected on all samples, and *S. aureus* on some samples, of naturally contaminated diapers and dishcloths (enterobacteria counts of the order of 7-9 log and 6-8 log per 4.7 cm^2 respectively; counts of *S. aureus* not stated) results indicated that residual contamination after laundering (and transfer to sterile items in the load) increased as the temperature of laundering decreased as follows:

- Of 6 trials at 60°C using an AOB powder, enterobacteria counts (ECs) were reduced to no detectable survivors in 5 of 6 trials (6th trial showed log 2 survivors). In all trials there was no transfer of Enterobacteria or *S. aureus* to sterile samples included in the load
- Of 6 trials at 40°C using a non AOB powder, residual ECs of 3-5 log per 4.7 cm^2 were recorded in all trials after laundering, and transfer of enterobacteria in 3/3 trials and *S. aureus* in 2/3 trials to sterile fabrics was recorded with residual counts up to 3-4 and 1-2 log per 4.7 cm^2 detected for enterobacteria and *S. aureus* respectively
- Of 8 trials at 30°C (4 with AOB and 4 with non AOB detergents) residual ECs of 2-5 log per 4.7 cm^2 were recorded after laundering in all 8 trials. Transfer of enterobacteria in 4/4 trials (but not *S. aureus*) to sterile fabrics was recorded with residual counts up to 1.5-2 logs per 4.7 cm^2 detected
- Of 8 trials at 15°C (2 with AOB and 2 with non AOB detergents) residual ECs of 3-5 log per 4.7 cm^2 were recorded after laundering in all 8 trials. Transfer of enterobacteria in 4/4 trials and *S.aureus* in 1/4 trials (using non AOB detergent) to sterile fabrics was recorded with residual counts up to 1-3 logs and 1.5 log per 4.7 cm^2 enterobacteria and *S aureus* respectively.

From these studies Terpstra *et al.* concluded that “the results show that hygienic quality of washing processes at low temperatures (15 and 30°C) leaves something to be desired”.

Gerba *et al.* 2001³¹ state that, during the course of their work, salmonella was detected on laundered undergarments from a child. Nordstrum, Reynolds and Gerba report a 2012 US study of samples from hospital operating room scrubs after use and after home-

¹ Enterobacteriaceae include species which may be of faecal origin such as *E. coli*, Klebsiella spp and Enterobacter spp, and are routinely used to assess potential risks associated with enteric pathogens. It must be borne in mind however that species of Enterobacter and Klebsiella may also originate from the environment).



laundering (no details of home laundering conditions are given).⁷⁴ Of unwashed swatches, 79% were positive for Gram +ve cocci, with 10% (3/29) of those classified as *S. aureus*; and 69% (20/29) tested positive for coliform bacteria, 3 of which were *E. coli*. After home laundering, 44% (18/41) of scrubs were positive for coliform bacteria, but none were *E. coli*, and no *S. aureus* was isolated. In their studies of naturally contaminated fabrics taken from hospitals, Blaser *et al.*⁷ found that, whereas before laundering of 345 isolates from soiled hospital laundry, 52 were *E. coli* and 5 were *S. aureus*, after laundering at 71°C and 22°C, 0/124 and 5/145 respectively were contaminated with *S. aureus*.

Other factors can also contribute to the exposure risk. Section 5.8 reviews data showing that contamination can spread from contaminated to sterile items included in the machine during laundering, which increases as residual contamination on laundered fabrics increases. The 2011 report¹ reviews data showing that transfer rates from moist contaminated fabrics to hands were around 1-10%, but in some cases this was as little as 0.1% or less, or as much as 50%, according to microbial strain, temperature, RH, type of fabric and inoculum size, and were significantly less (up to 10 fold decrease) if donor fabrics or hands were dry.

As stated above, the key question is whether residual pathogens or antibiotic resistant strains found on laundered fabrics are sufficient to represent a risk of establishing persistent carriage/colonization or clinical infection. In the 2012 IFH report,⁷⁵ data on “infectious doses” (number of organisms required to produce infection) of bacteria and viruses is reviewed. The data indicate that for some organisms infectious doses can be very low, particularly for viruses e.g the infectious dose of norovirus is estimated of the order of 1-10 particles.

Setting performance requirements for laundering

Overall the data discussed above suggests that deciding what might constitute “minimum hygiene performance standards” for home laundering based on microbiological and clinical data is not realistic at the present time. On one hand, there is insufficient data on bioburdens of pathogenic or resistant strains likely to be found on clothing etc. under normal daily wear or where someone is a carrier of pathogenic or resistant strains, whilst on the other it is impossible to define what may be considered a “safe” level of residual contamination after laundering i.e a level which could be considered as “non toxic”.

Because performance needs vary, it suggests that, if we are to avoid overuse of high temperature, laundry must be segregated into different categories according to level of risk, and different performance requirements set for each category. This principle is supported by the data of Terpstra *et al.*, as summarised above. They found that, whereas laundering of diapers and cloths (which were consistently and heavily contaminated with bacteria such enterobacteria) at 60°C with an AOB detergent reduced bacteria to undetectable levels and prevented transfer of contamination to other items in the wash, laundering at 40°C or below with a non AOB detergent did not. By contrast, their data indicated that handkerchiefs and socks were less frequently and less heavily contaminated with enterobacteria. Unfortunately, because contamination with enterobacteria was less frequent, the data was insufficient to establish the effectiveness of laundering against these items, but one experiment showed that a low level (1 log) EC on socks was reduced to undetectable levels by laundering at 60°C with an AOB detergent, but not by laundering with non AOB at 40°C. Much more data, involving a wider range of “normal wear or use” items such as shirts, underwear and socks is needed to determine the “after wear” maximum levels of organisms such as *S.aureus* shed from carriers, or enterobacteria shed from faecal material, or “after use” levels of faecal strains on cloths used in cleaning of toilets, or kitchen surfaces following food

preparation. Also to determine the effectiveness of low temperature in eliminating these naturally occurring bioburden levels from clothing etc. during laundering.

Without definitive data, which might allow us to set performance standards for laundering based on clinical and scientific principles, the only alternative is to use a pragmatic approach, whereby performance criteria are based on LRs which we could reasonably expect to achieve, given the factors and constraints which have to be taken into account (e.g the need to avoid excessive use of heat and water). The precedent for such an approach is seen in disinfectant testing where “pass” levels of 4 to 5 LR are set for standard suspension and surface tests, not based on clinical knowledge, but because it is known to be achievable, and from ongoing experience has been found to equate to containing the spread of infection.

Although our search identified a substantial amount of new data published since this issue was first addressed by IFH in 2002,² the data in this report suggests that, even adopting a pragmatic approach, the available data is still far from adequate (because of the extent of the variability) to be confident about what is the “baseline range” of LR values (the min-med-max profile) achieved by laundering under any given set of conditions (i.e LRs which we could reasonably expect to achieve). There is urgent requirement for a systematic study of the impact of the key variables, under conditions where other variables are carefully controlled, using standard methods such as DGHM,⁷⁶ ASTM⁷⁷ or CEN⁷⁸ methods.

10. IMPROVING THE EFFECTIVENESS OF LAUNDERING AT LOW TEMPERATURES

The data in this review suggests that giving a definitive answer to the questions – are conditions of laundering satisfactory to eliminate health risks associated with transmission via clothing and household linens?” and “is laundering at low temperatures associated with an increase in infection risk which is significant in public health terms?” is not a realistic approach, since infection risks and risk management approaches (and the lack of supporting microbiological data) do not lend themselves to assessing these risks in absolute terms. Set against this however the potential health benefit of maximising germ removal from hands and other surfaces such as fabrics (rather than setting performance requirements) is demonstrated by application of quantitative risk modelling as outlined in section 7.

In view of the current level of public health concern about infection risks associated with home and everyday life settings, particularly in relation to increasing healthcare now delivered at home to people who are infected or to vulnerable groups, there is growing awareness of the need to promote an effective multibarrier approach to hygiene in these settings⁷⁹ including appropriate safe laundering of clothing and household linens. As stated above, hygiene, both in the home and community as well as the hospital setting is also now being incorporated into strategies to reduce the spread of antibiotic resistant strains and the need for antibiotic prescribing. These aspects are reviewed elsewhere.^{79,75,80}

It is suggested that, given this situation, the more productive and prudent approach is to ensure that low temperature laundry cycles are operated in a way that compensates for any loss of effectiveness from laundering at these temperatures in order to ensure that microbiological quality of the textiles is achieved. As stated above, the data in this report suggests there are significant opportunities to achieve this through one or a combination of approaches. To achieve this, future studies need to take account of the following interrelated factors, which can act independently or synergistically to enhance the effectiveness of laundering by:

- Optimising detachment through detergency and mechanical agitation



- Optimising dilution through rinsing cycles
- Optimising chemical inactivation through the detergent/surfactant and other laundry product constituents, bearing in mind the need to also address concerns about antimicrobial resistance from persistent use of chemicals agents
- Ensuring that fabrics reach the specified temperature which is then suitably sustained throughout the cycle (i.e meets requirement of standard area under the curve assessment for heat processes). If it is correct that a significant part of the inconsistency in LR values recorded in this review is due to lack of control of key parameters, particularly temperature (also wash cycle time and number of rinse cycles) this in turn means that, much of the data in this review may underestimate what currently used cycles have the potential to deliver if these parameters were properly controlled.

In achieving satisfactory laundry performance for lower risk, normal wear clothing and household linens which come into close contact with the body (underwear, socks etc.) it must be considered to what extent it is necessary that these processes should demonstrate this capacity in the presence of “high load” soiling (as used in most studies reported here). Although it is appropriate that laundry processes for “high risk” items should achieve adequate performance in the presence of significant soil, as stated in section 8.2, this is not necessarily the case for underclothing and household linens which may be microbially contaminated, but not heavily soiled in a manner likely to compromise laundering effectiveness.

The following table summarises upper quartile LR values taken from the min-med-max profiles in Tables 7-9. They suggest the order of hygiene effectiveness (LR values) which ought to be consistently attainable (i.e. because they were attained in some studies) at each laundering temperature by ensuring that the specified parameters are consistently achieved and maintained in domestic washing machines i.e The ultimate aim should be to consistently achieve log reductions in the upper quartile of the min-med-max profiles for bacteria, viruses and fungi as suggested by the data in this report.

Temperature	Detergent	Achievable log reductions through the laundry wash and rinse cycle as indicated by min-med-max LR profiles in Tables 4.7.9 of the report		
		Bacteria*	Viruses*	Fungi*
60°C	Non AOB	N/A**	5.5- 6***	5-7***
	AOB	6-8		
40°C	Non AOB	4-5	3-7***	No data available
	AOB	6-8		
30°C	Non AOB	3-5	3-6***	4***
	AOB	4-7		

*When tested against suitable strains e.g bacteria: *S. aureus*, *Ent hirae*; virus: polio; fungi: *Trichophyton mentagrophytes*, *Candida* spp.

** N/A – not necessarily applicable if guidance is to always use AOB detergent, thereby maximising margins of safety

*** since min-med-max profiles suggests this is achievable in the absence of AOB, it must also be attainable when laundering at 60, 40 or 30°C c AOB detergent. Data from Heinzl suggests 5LR against polio at 30°C when using an AOB detergent

The data in section 8.4 indicates that a significant improvement in effectiveness of laundering could be achieved by ensuring that the machine load reaches the specified temperature, although further data is required to establish the extent to which the reported temperature shortfalls in modern machines compromise the hygiene effectiveness of domestic laundering.



11. DEVELOPING GUIDELINES FOR DOMESTIC LAUNDERING

The overall conclusion from the 2011 and 2013 IFH reports is that that clothing, household linens etc. are risk factors for transmission of potentially harmful microbes in the family home although they may be less than those associated with hands or other frequent hand and body contact surfaces. It is thus concluded that these risks need to be properly investigated, assessed and suitably managed as part of a multibarrier approach to home hygiene (as used in healthcare, food handling, manufacturing and other settings). The risks are such that home laundering should be able to both:

- Reduce the risk of transmission of infectious illnesses amongst family members
- Reduce the “silent” spread of antibiotic resistant strains such as MRSA (resident skin carriers), or multidrug resistant gram negative species which may be carried (e.g within the normal bowel flora) amongst healthy family members.

In response to current needs, IFH has developed guidance on home laundering of clothing and household linens. This is set out in Appendix 1. The proposed guidance is the consensus view of the IFH, based on the findings of this report, and the feedback of, and opinions expressed by the other members of the panel of experts who examined the report. The guidance is based on the assumption that the major sources of the organisms which need to be controlled are infected or colonised family members, domestic pets and food (mainly raw contaminated food).

IFH recognises that, whilst hygiene is important, equally it is important to consider sustainability issues i.e the environmental impact of higher temperature laundering, use of detergents and other chemicals, and the need to conserve water. The guidance is based on the principle that, if we are to minimise energy consumption associated with household laundering whilst at the same time managing infection risks, the items that make up the weekly wash need to be segregated into categories, with relatively more stringent laundering requirements specified for higher risk categories.

The detailed guidance set out in Appendix 1 is primarily intended for reference use by hygiene professionals/ infection control practitioners, community workers, professional and consumer media etc. who are called upon to give advice to their patients, or to the public in general, which is tailored to meet the specific needs of the individual patient or public group. For consumers/patients to be able to adopt this advice, the information needs to be interpreted, adapted and simplified to meet their individual needs, and transmitted through leaflets and/or one to one communication etc.

A key finding of this data review is the lack of standardisation of test conditions and the inconsistency in the published data which makes it extremely difficult to propose guidelines for home laundering with confidence, without first generating better data. Of particular concern, in trying to formulate advice for consumers is the data, as discussed in section 8.4, which suggests that, although recommendations can be given about preferred laundering temperatures, in reality modern washing machines do not reach the temperature which is specified on the machine controls. We are faced with the situation, however that, despite the significant gaps in data, we have to make decisions in the immediate term, and give advice to consumers (and those involved with developing washing machines, laundry detergents etc.) on laundering conditions which to the best of our knowledge will reduce infection risks to a level deemed appropriate in public health terms.

Although it could be argued that there is no clear epidemiological data which shows to what extent clothing etc. contributes to transmission of potentially harmful organisms in the home, or that lowering of laundry temperatures constitutes a health risk to consumers, there is extensive microbiological and epidemiological data demonstrating



some level of health hazard. Taking account of these considerations, IFH has concluded that the guidance should follow a precautionary approach, which incorporates a margin of safety against the current lack of standardisation and control of laundering parameters which means that typically some household cycles deliver significantly lower hygiene effectiveness than others.

This “prudent” approach is in line with the consensus view recently expressed by the expert group convened by the Rudolf-Shulke Foundation in Germany about proper surface decontamination in healthcare (Gebel *et al.* 2013⁸¹), which states “This (i.e. the microbiological and epidemiological evidence) underlines the need to perform proper surface decontamination procedures within a multi-barrier approach (a “bundle strategy”) to reduce and control pathogen transmission. This strategy should be implemented despite the existence of unresolved questions about the risks of environmental contamination. *Absence of definite evidence for a health hazard is not equivalent to evidence of absence of risk. If circumstantial evidence points to a putative health hazard, appropriate prudent action is legitimate policy for consumer protection.*”

The IFH guidance has thus been formulated to give consumers the best and most appropriate guidance based on current knowledge, taking account of both environmental and the need to protect consumer health. If we could understand more about the infection risks, the factors which contribute to the hygiene effectiveness of laundering, and how to better control domestic machine laundering parameters such as temperature in order to deliver that effectiveness, hopefully, in the longer term, it should be possible to recommend a less precautionary (i.e. less stringent) level of guidance, thereby further increasing the sustainability of the laundry process. As further discussed below, the data presented in this report suggests that this should be possible.

12. RECOMMENDATIONS FOR FURTHER WORK

In the immediate term, data is needed to ensure that current guidance on laundering of both lower and higher risk items is sufficient to protect consumer health. IFH judges that there is urgent need for the domestic washing machine and household care product manufacturers to commission studies to gain a better picture of the extent of the hazard to consumers, the relative efficacy of laundering under varying conditions of temperature, wash cycle and rinse condition, detergent formulation etc., and the ways in which the required parameters can be consistently delivered in a domestic washing machine.

The ultimate aim should be to consistently achieve log reductions in the upper quartile of the min-med-max profiles for bacteria, viruses and fungi as suggested by the data in this report. This data would also form a basis for developing new approaches/products/machine performance which could further reduce the stringency of the laundering parameters (temp, use of chemical, water consumption etc.) in a manner which further increases sustainability of the process:

- there is a requirement for more data on the bioburdens of potentially harmful strains (potentially pathogenic and antibiotic resistant strains) such as *S. aureus*, faecal (entero) bacteria, enteric and respiratory viruses, and fungi which are likely to be found on clothing etc., both under normal daily life conditions and under risk conditions e.g. where there is an infected person or a carrier and shedder of *S. aureus*
- there is need for studies of the effectiveness of laundering under well standardised and controlled conditions using standard methods such as DGHM,⁷⁶ ASTM⁷⁷ or CEN⁷⁸ methods. This should include studies of efficacy against typical enteric and skin bacterial strains, virus and fungi at 30, 40 and 60°C
- studies of the dose:response impact of temperature should include systematic evaluation of temperature profiles of laboratory and domestic machines, with particular



reference to standardising total energy input through the wash and how this impacts on effectiveness. There is need to better understand the extent to which performance of current models of domestic machines in relation to temperature control may be compromising the hygiene effectiveness of laundering

- the impact of detergency in mechanical removal of contamination from laundry through the wash and rinse cycles
- the impact of chemical inactivation during the wash cycle, particularly in relation to the impact of the surfactant and AOB constituents of laundry detergents
- the impact of soiling on hygiene effectiveness of laundering in relation to the levels of soiling typically found on normal day wear clothing in significant contact with the body, bearing in mind that for these lower risk items, levels of organic soiling relative to any microbial contamination level may be much lower than those used in studies reported in this review to assess the effectiveness of laundering at lower temperatures
- the relative hygiene effectiveness of laundering of artificially as opposed to naturally contaminated textiles.

Note: In this review no attempt has been made to assess risks associated with contamination which may build up in the machine itself, or the water used for rinsing. Although there is no data which suggests that this is a significant health risk in the domestic setting, it is important that this factor is not overlooked.



TABLES

Table 1 – Summary of estimates of log reductions on fabrics produced by water rinsing alone as compared with in the presence of detergent

T	Detergent (D) Water (W)	Sidwell <i>et al.</i> 1971	Wicksell <i>et al.</i> 1973	Wicksell <i>et al.</i> 1973	Wicksell <i>et al.</i> 1973	Blaser <i>et al.</i> * 1984	Smith <i>et al.</i> * 1986	Jaska <i>et al.</i> 1980	Davis/ Ainsworth 1989	Terpstra <i>et al.</i> * 2003	Davis <i>et al.</i> 1993	Heinzel <i>et al.</i> 2010	Lakdawala <i>et al.</i> 2011	Lakdawala <i>et al.</i> 2011	Gerhardts <i>et al.</i> 2009
		Poliovirus	<i>S. marcescens</i>	<i>S. aureus</i>	T3 phage			<i>S. aureus</i>	<i>E faecalis</i>		<i>E. faecalis</i>	poliovirus	<i>A. baumannii</i>	<i>S. aureus</i>	MS2 phage
wash cycle		N/S	20-35 min					13 min	7 min	Varied	7 min	60 min	N/S		20min
Rinse cycles		N/S	1					2	1	Varied	1	0	3		N/S
22°C	W					2.68-2.84									
27°C	W	0.7-2.2						0.38							
	D	1.2-5.6						0.7, 0.8							
30°C	W		1.63	2.07	2.28		1.5- 1.8					2.7	2.7	3.6	
	D		2.02	1.66	2.65							>5.48	2.3, 3.6 2.1,2.3	>7, >7	
38-40°C	W	1.7-5						1.91		1			3.4	4.9	2.8, 2.6
	D	2.4-6.3						3.4- 4.3					2.4,2.6, 2.7,2.7	>7, >7	6.9,3.9
50°C	W							5.76	2.4, 4.5		2.4, 4.5				
	D							4.6, 5.2	6.5, >7						
54-60°C	W	5.4						6.1					>7	>7	
	D	3.6-5.8						>4, >5					>7	>7	

*Naturally contaminated fabrics

Table 2 – Summary of results on effectiveness of laundering – tested against bacterial strains (transfer to sterile samples included in load:
- no transfer, + < 1 log, ++ 1-2 log, +++ >2 log)

	Wicksell 1973	Walter <i>et al.</i> 1975	Jaska Fredell 1980	Ainsworth 1989,1993	Block <i>et al.</i> 2001		Terpstra <i>et al.</i> 2003	Gerba <i>et al.</i> 2001	Fijan 2007*	
Initial log ct	5.5/23cm ²	7/6.5/cm ²	6-7/6.5 cm ²	7-8/1.5cm ²	9.2-9.8/ cm ²	8.4-8.6/cm ²	6-8/4.7 cm ²	8-8.6/7.6cm ²	6.5-7.5	
Test org	<i>S. aureus</i>	<i>S aureus</i>	<i>S. aureus</i>	<i>S. faecalis</i>	<i>S. aureus*</i> , <i>E. Faecium**</i>		Natural contamination - Enterobacteriaceae	<i>S. aureus</i>	<i>S. aureus</i>	<i>E. faecium</i>
Detergent	regular anionic detergent	liquid non ionic detergent	phosphate detergent, non ionic	Heavy duty detergent	Activated bleach detergents		Activated bleach detergent	non bleach detergent	Powdered detergent (P&G ultra)	Anionic and non ionic detergent
AOB	No	No	No	unlikely	Yes		Yes	No	No	No
Addition of soiling?	No	No	No	No	Defibrinated sheep blood	No	Defibrinated sheep blood		synthetic organic load	Various - Defibrinated blood, fat etc.
75-77°C										>6.4->7.5 >7.8
68-71°C	4 (+)									
60°C		7	>4.4, >5				6-8 (+/-)			4.5-4.8 1.3-1.4
54-57°C	4 (+)	6								
49- 50°C		6.5,6.7,6.8	4.5, 5.2	>7 (-),>7(+), 6.52(+++)						
45-46°C	3 (+)									2-2.6 1
40°C								3-5(++)		
38°C		3,3,4.3	2.85,3.0,4.3							
35°C	1.5 (++)									
30-31°C				5 (+++),5	*3.1, 4.2, **1.9, 2.6 (+)	*3.9, 7.2, ** 3.0, 3.8(+)	3-5 (++)	2-4 (++)		
27°C			0.4, 0.83, 0.77							
20-24°C	1.5 (++)								3.2 (+)	
15°C				3. 5 (+++) (+)			1.5-3 (+++)	2.5-4 (+++)		

*Fijan *et al.*: samples were tested after machine washing without rinsing

Table 4 – Summary of LR data on the impact of temperature on the effectiveness of laundering on fabrics contaminated with fungi

Temp	LR values						
	Block <i>et al.</i> 2001*		Fijan <i>et al.</i> 2007	Hammer <i>et al.</i> 2010		Ossowski & Duchmann 1997	Ossowski & Duchmann 1999
	CA	TM	CA	CA	TM	TM	CA
60°C			>6 to >7.5	>5.36	>5.36		NDS
45°C			2.0				
40°C							S/NDS***
30°C	2.6,2.2,2.4	0.8,2.2,1.3		>5.67	2.56	NDS	S
30°C**	3.9	4.1					

CA = *C. albicans*, TM = *Trichophyton rubrum* *AOB detergent was used in this study; **in absence of soil; ***varied according to strain; S = survivors detected; NDS = no detectable survivors

Table 5 – The effects of drying after laundering of fabrics on log reductions in microbial contamination

	Test organism/s	Drying conditions	Estimated increase in LR due to drying
Sidwell & Dixon 1969	Polio and vaccinia virus	20h at 25°C	>2.2-3.1
Sidwell <i>et al.</i> 1971	poliovirus	20h at 25°C after laundering at: 54-60°C 38-43°C 21-27°C	0-0.4 0-3.7 0-4.5
Wicksell <i>et al.</i> 1973	<i>S.aureus</i> , <i>S. marcescens</i> , <i>B.stearothermophilus</i> , T3 bacteriophage	20 min drying in automatic dryer at 40°C, cool for 10 min	Up to 1.69 Up to 3.84 Up to 3.23 Up to 0.97
Walter and Schillinger 1975	<i>S aureus</i>	Gas dryer 16 min medium temp after washing at 38°C 49° or more	2.36-2.89 01.5-2.17
Smith <i>et al.</i> 1985	Naturally soiled laundry – total counts determined – probably included spore former bacilli	94°C for 25 min with a 5 min tumble cool 175-178°C in a dynamic tumble dryer	0.39 and 0.58 0.69 and 0.81
Gerba <i>et al.</i> 2001	<i>S aureus</i> , <i>S typhimurium</i> <i>Mycobacterium fortuitum</i>	Drying at 55°C for 28 and 43 mins respectively	+1.03, 1.15 >2.04 2.77, 2.20 +2.5, +2.7
Gerba and Kennedy 2007	adenovirus, rotavirus, hepatitis A virus	28 mins (at room temp?)	about 0.1 log up to 1.4 log for adenovirus
Linke <i>et al.</i> 2011	<i>S. aureus</i>	24 hours at room temperature	No further LR

Table 6 – Summary of LR data on the impact of temperature on effectiveness of laundering with non AOB detergents on fabrics contaminated with vegetative bacterial strains

Temp	N	LR values obtained from studies as summarised in Tables 1 and 2		
		Min	Median values shown in bold	Max
60°C*	11	1.75	>3, 4.22, >4.4, >5 , >5,>5, >5, >7,	7
49-50°C	8	4.5	5.2, 6.5, 6.5 , 6.7 , 6.8 , >7,	>7
38-40°C	17	0.54	2.0,2.3, 2.4,2.5,2.6,2.7,2.7, 2.85 , 3.0 , 3.0,3.4,4.2, 4.3, 5.0, >5	>5
30-31°C	17	0.5	<1,1.2,1.66, 2.0,2.02,2.1,2.3, 2.3 , 2.3,2.4,3.6,4.0, 5.0,5.0 >5	>5
15-24°C	8	0.3	1.5,1.5, 2.5 , 3.0 , 3.2, 3.5,	4

*LR Values of 1.3, 1.4, 4.5,4.8 obtained by Fijan *et al.*, 60°C cycle, have been omitted because they represent LR during the wash cycle only (i.e samples were taken at the end of the cycle, before rinsing)

Table 7 – Summary of LR data on the impact of temperature on the effectiveness of laundering with non-AOB detergents on fabrics contaminated with viruses

Temp	N	LR values obtained from studies as summarised in Table 3		
		Min	Median value shown in bold	Max
54-60°C	3	3.6	3.7	5.8
35-46°C	6	2.4	2.7, 3.1 , 3.96 6.3	6.82
30-31°C	*			
21-27°C	8	1.2	1.2, 2.0, 2.2 , 2.3 , 2.6, >3.6,	5.6

*No data available for 30°C

Table 8 – Summary of LR data obtained during laundry cycles using water only without detergent

Temp	N	LR values obtained from studies as summarised in Table 1		
		Min	Median values shown in bold	Max
38-40°C	5	1.91	2.6, 2.8* , 3.4	4.9
27-30°C	9	0.38***	1.5, 1.63, 1.8. 2.07** , 2.2, 2.28, 2.7, 2.7	3.4

*compared with median LR value 3.0 for machine laundering with non-AOB detergent at 38-40°C;
 **compared with median LR value 2.3 for machine laundering with non-AOB detergent at 27-30°C;
 ***this value was obtained by Jaska and Fredell where rinse and drain rather than rinse and spin cycles were use



Table 9 – Summary comparing LR data on the effectiveness of laundering with AOB and non-AOB detergents on fabrics contaminated with vegetative bacterial strains

Temp	Detergent type	N	LR values obtained from studies as summarised in Table 1 and 2		
			Min	Median value shown in bold	Max
60°C	AOB	6	1.92	>3, 6, >6 , 8.0	8.18
	Non AOB	11	1,75	>3, 4.22, >4.4, >5 , >5,>5, >5, >5,	>5
38-40°C	AOB	4	2	>3, >6	8.06
	Non AOB	17	0.54	2.0,2.3, 2.4,2.5,2.6,2.7,2.7, 2.85 , 3.0 , 3.0,3.4,4.2, 4.3, 5.0, >5	>5
30-31°C	AOB	13	0.14	1.9,2.6,3.0, 3.0, 3.0, >3.0 ,3.1, 3.8,3.9, 4.2,5.0	7.2
	11	18	0.3	0.5,<1,1.2,1.66, 2.0,2.02,2.1,2.3, 2.3 , 2.3, 2.4,3.6,4.0, 5.0, 5.0 >5	>5

Table 10 – Summary of laundering conditions used in the different studies of efficacy of laundering

	Wash cycle time mins	Number of rinses	Type of machine
Jordan <i>et al.</i> 1969	10	NS	NS
Sidwell and Dixon 1971	14	2	NS
Wicksell <i>et al.</i> 1973	20	1	NS
Walter and Shillinger 1975	NS	2	NS
Jaska and Fredell 1980	13	2	NS
Davis/Ainsworth/Fletcher 1989,1993	7	1	NS
Gerba <i>et al.</i> 2001	12	3	Domestic
Block <i>et al.</i> 2001	40-60	3	Domestic
Terpstra <i>et al.</i> 2003 (Lab studies)	30	3	Wascator
Terpstra <i>et al.</i> 2003 (studies with domestic machines)	NS	NS	Domestic
Lichtenburg <i>et al.</i> 2006	NS	NS	NS
Patel <i>et al.</i> 2006	NS	NS	Domestic
Gerba and Kennedy 2005	12	1	Heavy duty machine
Hammer <i>et al.</i> 2010	10min prewash, 10	1	NS
Linke <i>et al.</i> 2011	NS?	NS?	Washer extractor
Gerhardts <i>et al.</i> 2009	20	NS	NS
Heinzel <i>et al.</i> 2010	60	none	Front load washing machine
Lakdawala <i>et al.</i> 2011	10-20	3	Electrolux c. control to ensure temperature sustained at preset value through cycle

NS – not stated



APPENDIX 1. GUIDANCE ON MACHINE LAUNDERING OF CLOTHING AND HOUSEHOLD LINENS IN THE HOME SETTING

This guidance is based on the assessment that clothing, household linens etc. are risk factors for transmission of potentially harmful microbes in the family home, which, although these risks may be less than those associated with hands or other common hand touch surfaces, nevertheless need to be properly assessed and suitably managed in accordance with the level of risk. It is concluded that home laundering should be able to both:

- Reduce the risk of transmission of infectious illnesses amongst family members
- Reduce the “silent” spread of antibiotic resistant strains such as MRSA (resident skin carriers), or multidrug resistant Gram negative species (e.g. NDM-1, ESBL-producing strains which may be carried e.g. within the bowel flora) amongst healthy family members.

This detailed guidance is primarily intended for reference use by hygiene professionals/ infection control practitioners, community workers, professional and consumer media etc. who are called upon to give advice to their patients, or to the public in general, For consumers/patients to be able to adopt this advice, the information needs to be interpreted, adapted and simplified to meet the specific needs of the individual patient or public group, and transmitted through leaflets and/or one to one communication etc.

The guidance is based on the assumption that the major sources of the organisms which need to be controlled are infected or colonised family members, domestic pets and food (mainly raw contaminated food)

The guidance is based on the principle that, if we are to minimise the overall energy consumption associated with household laundering whilst at the same time managing infection risks, the items that make up the weekly wash need to be segregated into categories according to level of risk, and relatively more stringent laundering requirements specified for higher risk categories.

Categorization of laundry items according to level of risk

It is recommended that clothing, household linens etc. should be divided into the following categories according to the level of risk:

Category A. Higher risk items

Category A1

Specific items of clothing, household linens etc. where there is considered to be a higher risk that they may have become contaminated with pathogens or antibiotic resistant strains during normal daily use or wear including:

- Uniforms of healthcare workers and clothing of other workers who are likely to come into contact with pathogens, which are laundered at home e.g. restaurant, laboratory and sewage workers, veterinarians, farmers, etc.
- Clothing of family members giving care to infected family members
- Clothing etc. which is heavily soiled e.g. with faeces or vomit, or body fluids (including re-usable babies’ nappies)
- Sports clothing, particularly high-contact sports such as rugby football, American football, martial arts, etc.
- Cloths and towels used in the kitchen during food preparation, the nursery etc.
- Clothing of patients in hospitals, which is taken home by the family for laundering
- Clothes of patients with chronic wounds (up to 1 - 2 % of every old people will have chronic wounds which can be heavily contaminated *with Staphylococcus aureus* and *Pseudomonas aeruginosa*)



- Clothing of family members with skin diseases such as dermatitis, who may be heavy shedders of e.g. *S. aureus*
- Fabric items associated with domestic pets e.g. pet blankets.

Category A2

All items of clothing, household linens etc. used or worn in situations where there is higher infection risk:

- because someone in the home is infected - e.g. shedding bacterial pathogens in faeces, or fungal pathogens such as in athlete's foot from their skin, or *Candida* from mucous membranes
- because there is someone in the home who is particularly vulnerable to infection e.g. undergoing cancer chemotherapy, HIV/AIDS etc.

Category B. Lower risk items

Category B1

Those items of normal daily wear which come into direct, significant and persistent contact with body surfaces during normal daily wear (see endnote i) This includes:

- underclothing (including socks, vests, bras, pants), sweat shirts, towels, bed linens, face cloths and other personal items.

Category B2

Those items of normal daily wear outer clothing which do not have extensive contact with body surfaces. This is considered to apply to items such as:

- jackets, sweaters, skirts, trousers, soft furnishings, table linens etc.

Where category B items are being used or worn in "risk" situations as designated as Category A2 above (i.e. where a family member is infected, or at increased risk of infection) they should be considered as category A and laundered as per instructions for laundering of Category A.

Guidance for laundering of Category A and Category B items

The following conditions for laundering are recommended:

Laundering of Category A items.

It is recommended that these items should always be machine laundered at 60°C or more, using an oxygen bleach-based laundry product (see endnotes ii and iii). The hygienic effectiveness of laundering under these conditions depends on ensuring that:

- the machine is not overloaded i.e. is loaded according to instructions
- the correct dosage of detergent is added according to pack instructions,
- the machine, load and wash water is heated to, and reaches 60°C, prior to commencement of the cycle (see endnote iv).
- a standard wash cycle is used (i.e. avoid a "quick wash", "water saving" or other "eco" cycles)
- the load is subjected to at least 2, preferably 3 rinse and spin cycles



Notes:

1. Laundering at 60°C should be possible for most Category A1 items because of the types of fabrics which are used.
 - For some items, particularly in Category A2 (delicates, coloureds or woollens), it may not be possible to wash at these temperatures and/or to use a bleach-based detergent. For these items the following is recommended:
 - Carry out a prewash by soaking clothes in cold water with non oxygen bleach-based detergent. Drain off as much wash liquid as possible and if possible wring out. Then wash at 30-40°C according to instructions on the care label.
 - The hygiene effectiveness of the process may be increased by using an antimicrobial prewash product or hygienic rinse aid according to manufacturer's instructions and claims guidance on efficacy (i.e its efficacy against bacteria and/or viruses and/or fungi etc.)
 - For items which are not sensitive to bleach, chlorine bleach (1 cup of household bleach diluted to 2 pints water) may be added to the final rinse cycle to give an additional level of hygiene assurance
 - In some cases it may be advisable to use a professional laundering service in order to achieve adequate hygiene.

2. Segregation of laundry

Although the evidence suggests that laundering of items at 60°C with an AOB detergent is sufficient to prevent transmission of any pathogens between different items within the same wash load, because of the "risk status" of these items it is advised that Category A items are segregated into separate loads e.g.

 - Launder items used around food, e.g. tea towels and dishcloths, separately from other items.
 - Launder items from a known infected person, or items visibly/heavily soiled with blood, faeces or potentially infected body fluids separately from items for other family members
 - Uniforms of healthcare and other designated workers should be laundered separately from other laundry items.

3. Hygienic quality assurance of these items can be further increased (i.e. the margin of safety) by:
 - Drying in sunlight
 - Tumble drying at 40°C or more, for 20 minutes or more (see endnote v).
 - Ironing – particularly steam ironing

4. Where a family member is known to be infected with *Clostridium difficile*, laundering of soiled items at 60°C with an AOB detergent is not sufficient. In this situation, local infection control teams should be consulted on the most appropriate methods for decontamination.

5. Heavily soiled items. As stated above, it is advised that items soiled with blood, vomit, etc. should be laundered at 60°C with an AOB detergent. By contrast items heavily soiled with food material (unless it is uncooked raw foods such as raw meat or chicken), mud etc. may appear very dirty but are not necessarily contaminated with high levels of pathogens. However it may be necessary to launder these items at 60°C with an AOB detergent in order to achieve the desired level of visible cleanliness



6. Additional guidance:
 - Wear disposable latex gloves when handling laundry if it is visibly soiled.
 - Remove residual solid material with a tissue and placing it in the toilet before laundering or washing.
 - Sluicing (hand-washing dirty linen before putting it in the washing machine) is not recommended as this can create aerosols that may contain pathogens.
 - Wash hands after handling soiled laundry.
 - Dry laundry as soon as possible after washing.
7. House dust mites. House dust mites which can cause allergies can build up in all types of household textiles. Laundering at 60°C with an AOB detergent is recommended to reduce the risk.

Laundering of Category B items

Category B1 items

It is recommended that these items should be machine laundered at 30-40°C, using an oxygen bleach-based laundry product (see endnotes ii and iii). The hygienic effectiveness of laundering under these conditions depends on ensuring that:

- the machine is not overloaded i.e. is loaded according to instructions
- the correct dosage of detergent is added according to pack instructions,
- the machine, load and wash water is heated to, and reaches 30 or 40°C, prior to commencement of the cycle (see endnote iv)
- a standard wash cycle is used (i.e avoid a “quick wash”, “water saving” or other “eco” cycles)
- the load is subjected to at least 2, preferably 3 rinse and spin cycles.

Category B2 items

For **category B2** items, which are considered as “lower risk” (i.e. excluding in situations where family members are infected, or at increased risk of infection), although laundering at 30°C with a non AOB detergent is considered to deliver limited decontamination, this is considered satisfactory for these items.

Notes:

1. Although laundering at 30-40°C with an oxygen bleach-based detergent may be possible for many/most Category B1 items, for some items, particularly delicates or coloreds, it may not be possible to wash at these temperatures and/or to use a bleach-based detergent. For these items the following is recommended:
 - Carry out a prewash by soaking clothes in cold water with non oxygen bleach-based detergent. Drain off as much wash liquid as possible and if possible wring out. If it is not feasible to launder at the specified temperature/detergent, items should be washed according to instructions on the care label.
 - The hygiene effectiveness of the process may be increased by use an antimicrobial prewash product or hygienic rinse aid according to manufacturer’s instructions and claims guidance (i.e. on efficacy against bacteria and/or viruses and/or fungi etc.)
2. Segregation of laundry - Evidence suggests that laundering of items at 30-40°C may be insufficient to prevent transmission of any pathogens between different items within the same wash load. It is thus advised that Category B1 and B2 items are segregated into separate loads and laundered separately.



3. Hygienic quality assurance of these items is further increased by:
 - Drying in sunlight
 - Tumble drying at 40°C or more, for 20 mins or more (see endnote v)
 - Ironing – particularly steam ironing

Further Guidelines for all laundry

- Wash hands after handling soiled laundry.
- Dry laundry as soon as possible after washing. Don't leave it damp for long periods, e.g. in the washing machine overnight, because any remaining microbes may multiply quite rapidly. In particular, although these are not harmful, this particularly includes microbe which impart unpleasant odours to the textiles
- In large houses or apartment buildings, laundry facilities are shared by all residents/householders thereby increasing the risk of transfer considerably. If using shared laundry facilities, e.g. a laundrette, always use a bleach-based product and launder at 40-60°C.

Care of the washing machine

Particularly for washing machines which are only run at 30-40°C with a non AOB detergent, bacterial and fungal biofilms will build up in the machine. Although, as yet there is no evidence that these species are harmful to health in the domestic setting (although a 2013 infection outbreak in low birth neonates associated with this source has been reported in a hospital (Exner pers comm)), these microbes can be transferred in large numbers to the clothes etc. They can also impart strong and unpleasant odours to the textiles. The washing machine should be cared for as follows:

- Keep your washing machine clean - including rubber lining which should preferably be cleaned with a weak bleach solution (1 cup of household bleach to 2 pints water)
- Rinse and scrub detergent box weekly - if need be use boiling water
- Open the door and the detergent box when the washing machine not in use to enable inner surfaces of the washing machine to dry.
- Once a week or every fifth cycle, use a high temperature wash, or alternatively a chemical disinfectant on an empty cycle, to clean the interior of the machine the machine and prevent the development of odours which are not necessarily harmful, but unacceptable. In order to reduce this build up, the machine should be run with the program with not only the highest wash temperature as specified in the documentation; but also the highest detergent level and the longest washing time. This is because research has shown that at a normal low suds level the 'hot' water will not heat and clean the inner of the machine sufficiently.

Endnotes

- i. It is not possible to compile an exhaustive/definitive list of which items fall in this category and which fall in category B1. It is left to health worker/consumer interpretation, bearing in mind that, in some cases it could lead to some small increase in risk
- ii. During laundering, chemical inactivation of microbes on fabrics can be achieved using various bleach components. Normally today oxygen bleaches (persalts) with a low temperature activator are used or, as is common in some countries, chlorine-based bleaching agents are added to the wash load. General-purpose laundry detergent powders typically contain a bleach system, usually based on active oxygen delivered via percarbonate together with a bleach activator such as TAED. The primary purpose of the active oxygen bleach is to achieve better cleaning and improved whiteness of the laundry. Oxygen-based bleaches however, also produce some chemical inactivation of bacteria,



fungi and viruses, and the surfactant itself will also exert some chemical inactivation action against certain species. The extent of this action will depend on the concentration, wash temperature, pH, level of soiling etc. The rate and extent of release of active oxygen and thus the microbiocidal action decreases as the wash temperature decreases, but bleach activator manufacturers claim that effective bleaching action can be delivered even at temperatures down to 20°C. If a domestic laundry product is “oxygen bleach-based”, the term “oxygen-based bleaching agent” is listed as one of the ingredients on the pack. As summarized in the table below, as a rule, powders and tablets are bleach-based, but liquids, and products used for “coloreds” are not. For more information go to: http://uk.cleanright.eu/index.php?option=com_content&task=view&id=112&Itemid=143&Itemid_fourth=130

	Powder / Tablets					Liquids				
	Bio		Non-bio		Colour	Bio		Non-bio		Colour
'bleach'	+	+	+	+	-	-	-	-	-	-
Enzymes	+	+	-	-	+/-	+	+	-	-	+/-

- iii. An alternative process may be used provided it can be demonstrated through scientifically valid in vivo method, that it delivers an equivalent level of effectiveness against bacteria fungi and viruses.
- iv. It should be noted that, in some countries e.g. USA water at the given temperature is added to the machine prior to adding the clothing. This means that the temperature of the load during the wash cycle is likely to be well below this initial temperature throughout the wash cycle
- v. It must be borne in mind that tumble drying is not recommended as a measure to achieve hygiene due to its poor sustainability



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