ARCH 602 Crafting a Dissertation
1. Critically reading and writing articles
2. Visual display of quantitative information

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Goals for today

- Convince you of the importance of critically reading and writing articles, as well as effective data display (if that would help you in your work)
    - Focus is on 'technical' reading and writing because that's my field, but it mostly translates to other fields too

- Show you some tips and tricks that I've learned over the years that have helped me in all three areas

Why technical reading and writing?

- Although we spend most of our time thinking about technical content – theories, applications, software, etc. – we also have to communicate our designs/analyses to various stakeholders

- We use a combination of oral, visual, and written communication

- Common forms of written communication include:
    - For those in academia:
        - Publishing articles in journals and conferences
        - Writing other pieces like commentaries, editorials, op-eds, and magazine articles
    - For those in industry:
        - Writing technical reports, memos, and briefs

Technical writing: Our currency for communication

In Academia: peer-reviewed journal articles

Large losses of total ozone in Antarctica reveal seasonal ClO_x/NO_x interaction

J. C. Farman, B. G. Gardiner & J. D. Shanklin
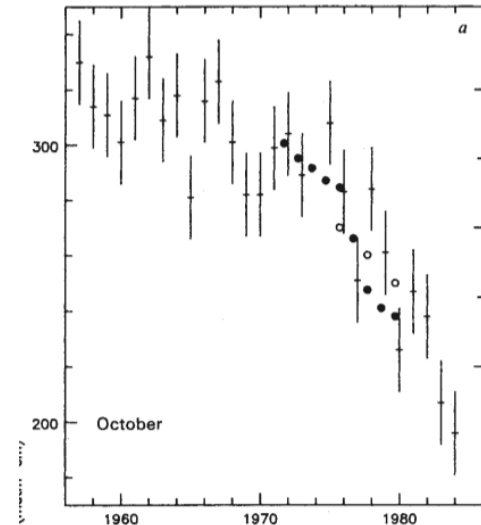
MOLECULAR STRUCTURE OF NUCLEIC ACIDS

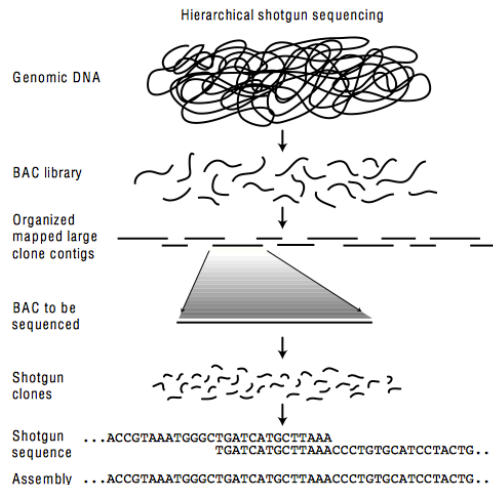### A Structure for Deoxyribose Nucleic Acid

No. 4356   April 25, 1953   NATURE

J. D. WATSON
F. H. C. CRICK

http://www.nature.com/nature/dna50/watsoncrick.pdf

http://www.nature.com/nature/journal/v315/n6016/pdf/315207a0.pdf

Hierarchical shotgun sequencing

Genomic DNA

BAC library

Organized
mapped large
clone contigs

BAC to be
sequenced

Shotgun
clones

Shotgun   ...ACCGTAAATGGGCTGATCATGCTTAAA
sequence   TGATCATGCTTAAACCCTGTGCATCCTACTG...

Assembly ...ACCGTAAATGGGCTGATCATGCTTAAACCCTGTGCATCCTACTG...

Initial sequencing and analysis of the human genome

International Human Genome Sequencing Consortium*

http://www.nature.com/nature/journal/v409/n6822/pdf/409860a0.pdf

Technical reading: What I read (and publish in)

General air pollution and other environmental
- *Environmental Science and Technology*
- *Atmospheric Environment*
- *Aerosol and Air Quality Research*
- *Journal of Aerosol Science*
- *Aerosol Science and Technology*
- *Environmental Pollution*
- *Chemosphere*
- *Journal of the Air and Waste Management Association*

Buildings
- *Indoor Air*
- *Building and Environment*
- *Energy and Buildings*
- *HVAC&R Research*
- *ASHRAE Transactions*
- *ASCE Journal of Architectural Engineering*
- *Construction and Building Materials*

Other
- *Sensors*
- *PLoS ONE*
- *ISME Journal*
- *Risk Analysis*

Energy systems (conversion, storage, etc.)
- *Solar Energy*
- *Renewable Energy*
- *Energy Policy*
- *Energy*
- *Applied Energy*
- *Energy Conversion and Management*

Environmental Health
- *Environmental Health Perspectives*
- *Journal of Exposure Science and Environmental Epidemiology*
- *Inhalation Toxicology*
- *Journal of Occupational and Environmental Hygiene*
- *Annals of Occupational Hygiene*
- *Clinical Infectious Diseases*
- *Journal of Infectious Diseases*
- *Epidemiology*
- *American Journal of Epidemiology*

Technical writing: Our currency for communication

In industry: technical reports

TECHNICAL READING & WRITING

Tips and tricks

Technical writing: The process

- Technical writing starts with technical reading
  - Your research directions and goals must be informed by and grounded in the existing literature
  - Need to be able to critically read technical articles

- Then, after you design and perform your experiments/simulations (based on prior readings), collect data, and analyze, you need to be proficient in being able to tell a story via writing, tables, and figures
  - Following the formatting guidelines of the journal you intend to submit to or the report template you have to follow

- This goes out for review and with some luck, you'll get published
  - The peer review process is a story for another day

- *Editing* is easier than writing, so don't be afraid to put words – any words – on the page and edit them later

Reading technical articles

- I have found "active" or "deliberate" reading to be very useful

- Go in to an article with a mission – something you want to learn specifically

- Worry about the details once you see the results

In practice: When I was a graduate student…

When I was a graduate student…

A Concentration Rebound Method for Measuring Particle Penetration and Deposition in the Indoor Environment

Tracy L. Thatcher, Melissa M. Lunden, Kenneth L. Revzan, Richard G. Sextro, and Nancy J. Brown
Lawrence Berkeley National Laboratory, Environmental Energy Technologies Division, Berkeley, California

[Handwritten annotations: 1) Decay → loss rate 2) Flush by HEPA supply 3) Stop pressurization; measure rebound]

Continuous, size resolved particle measurements were performed in two houses in order to determine size-dependent particle penetration into and deposition in the indoor environment. The experiments consisted of three parts: (1) measurement of the particle loss rate following artificial elevation of indoor particle concentrations, (2) rapid reduction in particle concentration through induced ventilation by pressurization of the houses with HEPA-filtered air, and (3) measurement of the particle concentration rebound after house pressurization stopped. During the particle concentration decay period, when indoor concentrations are very high, losses due to deposition are large compared to gains due to particle infiltration. During the concentration rebound period, the opposite is true. The large variation in indoor concentration allows the effects of penetration and deposition losses to be separated by the transient, two-parameter model we employed to analyze the data. For the two houses studied, we found that as particles increased in diameter from 0.1 to 10 μm, penetration factors ranged from ~1 to 0.3 and deposition loss rates ranged from 0.1 and 5 h^{-1}. The decline in penetration factor with increasing particle size was less pronounced in the house with the larger normalized leakage area.

INTRODUCTION

Particulate air pollution is associated with increased morbidity and mortality even at the generally low levels of air pollution found in United States cities (Dockery et al. 1993;

Pope et al. 1995; Samet et al. 2000). The exact compounds and/or particle size ranges responsible for these health effects have not yet been determined. The indoor environment provides a significant, if not dominant, exposure potential for particles for two primary reasons. First, people spend most of their time indoors—typically ~90% (Jenkins et al. 1992; Robinson and Nelson 1995). Second, indoor concentrations of particles of outdoor origin are estimated to be on the same order as outdoor concentrations (Wallace 1996; Ott et al. 2000; Riley et al. 2001). Indoor concentrations of particles of outdoor origin are influenced by many building and environmental factors, such as air leakage rates and ventilation system design. Thatcher et al. (2001) identified and evaluated sources of data for those factors that affect the transport into and concentration of outdoor particles within the indoor environment. In addition to particles of outdoor origin, particles generated from indoor sources, such as tobacco smoke, cooking fumes, or pet dander, may present significant specific health concerns and may add to the total health burden associated with particle exposures.

Particle deposition within the home will reduce indoor airborne concentrations of particles with both indoor and outdoor origins. For this reason, understanding deposition loss rates under typical residential conditions is important for assessing human health impacts from indoor particles. Many experiments have been performed to study particle deposition in the indoor environment (Offermann et al. 1985; Xu et al. 1994; Byrne et al. 1995; Thatcher and Layton 1995; Fogh et al. 1997; Abt et al. 2000; Long et al. 2001; Vette et al. 2001; Mosley et al. 2001; Thatcher et al. 2002). Results from these studies show a wide degree of variability in deposition rate for any given particle size. This variability is due, at least in part, to variations in the conditions under which deposition rates were measured; Factors such as airflow conditions, quantity and nature of furnishings, interior surface-to-volume ratio, surface-to-air temperature differences, particle stability, and measurement method may all be expected to influence the measured deposition rate.

[Handwritten annotation: variability in measured β values]

Another key factor influencing indoor exposures to particles of outdoor origin is the effect of losses due to particle filtration by the building shell. These losses are typically quantified by the use of a penetration factor, P, defined as the fraction of particles in the infiltrating air that pass through the building shell. Previous experiments on penetration factors have found a large variation in values. In some cases, it appears these variations are due to the variability found in houses and in experimental conditions. In other cases, the results are confounded by the inability to separate deposition and penetration effectively and to account for time dependencies in the underlying measured values. Thatcher and Layton (1995) measured particles as a function of size and found penetration factors near 1 for particles with diameters larger than 1 μm for the single residence studied. These results suggested that the shell of the building studied provides essentially no filtration for these particles. However, this study was performed using only a small number of replicates in a single residence and may not be representative of the general building population. Wallace (1996) also calculated penetration factors very close to 1 for PM 2.5 and PM 10, based on the particle mass data from the EPA PTEAM study for a large number of households in the Los Angeles area. These data do not lend themselves to understanding whether particle penetration is particle-size dependent. Cristy and Chester (1981) generated large quantities of 2 μm-diameter spores outside a trailer home, which are often poorly sealed structures, and measured the indoor concentration response. Based on their data, they conclude that penetration losses did not have a significant effect on indoor concentrations. Vette et al. (2001) reported penetration factors for a single house between 0.4 and 0.9 for ambient particles with diameters between 0.01 and 2.5 μm. However, they did not measure air exchange rates during the period for which the penetration rates were calculated. Because air exchange rates vary from period to period, their results have a large uncertainty associated with them. Thatcher and Layton (1995), Wallace (1996), and Vette et al. (2001) all based their results on measured ambient particle concentrations. Ambient outdoor particles may undergo unknown reactions and/or transformations in the indoor environment that can complicate interpretation of results. As we discuss further below, this is particularly important in the western U.S., where volatile ammonium nitrate particles can represent a significant portion of the particle mass.

Abt et al. (2000) calculated a factor they termed the "effective penetration efficiency," which combines both deposition and penetration losses for outdoor particles. However, their analysis did not separate the two factors. Long et al. (2001) described an "infiltration factor" which was equivalent to the "effective penetration efficiency" discussed above, where the effects of deposition and penetration losses are not separated. They also determined values for deposition and penetration losses using a random effects mixed model on data from nine homes and reported penetration factors between about 0.9 and 0.3 for particles between 0.02 and 6 μm, respectively. They reported penetration values for one individual home where the "windows and doors

were predominantly left open." As the particles increase in diameter from 1 to 6 μm they report that modeled "penetration efficiencies drop precipitously" (P = 0.9, 0.82, 0.74, 0.69, and 0.53 for particle diameter bins 1–2, 2–3, 3–4, 4–5, and 5–6 μm, respectively). The low values for the larger particle sizes seem physically unreasonable, since when windows are open nearly all of the air exchange will occur through the open windows, where the penetration factor will be 1. A potential reason for the incongruity using their approach is that the method fits a single value of penetration factor to all of the data, regardless of whether windows and doors are open or closed. Since homes will tend to have higher air exchange rates (and penetration factors near 1) when windows are open and lower air exchange rates when windows are closed, a single value for P cannot be used to fit the entire data set. Additionally, Long et al. used a steady-state model to analyze their data. However there is no indication that the indoor concentration was constant over time ($dC_i/dt = 0$), as required by a steady-state model or an analysis of the effect of using a steady-state model to analyze nonsteady data.

Roed and Cannell (1987) reported P = 1 for two radioactive isotopes (^{131}I and ^{7}Be) and P = 0.53 for a third (^{137}Cs), all assumed to be bound to particles, based on measurements in a single house. Koutrakis et al. (1992) measured PM 2.5 in 394 homes and estimated penetration factors between 0.58 and 1.04 for 8 elements primarily of outdoor origin. Their calculations assumed that all 8 elements had an average deposition velocity of 0.18 m/h—in effect, that the elements were all associated with the same size particle. If the elements were truly associated with the same particle size, then the reason for the differences in penetration factors between elements is unclear. If they are associated with different particle sizes, then the assumption of a common deposition rate, independent of particle size, will lead to large errors in the calculation of penetration factors. This will be especially true for particles larger than 1–2 μm in diameter (Thatcher et al. 2002).

Chao and Tung (2001) report P = 0.85 based on measurements of PM 2.5 in five homes and the assumption that indoor deposition losses (β) were negligible. Consequently, their reported penetration factor attributes both penetration and deposition losses to building shell filtration and therefore overstates the penetration loss rate. Tung et al. (1999) measured concentrations of PM 10 in an interior conference room and corridor of an office building under conditions with the HVAC off and calculated penetration factors for transport from the corridor into the adjacent room ranging from 0.69 to 0.86. Their data show that a large increase in the particle concentration in the corridor did not cause any response in the conference room concentration, which they attribute to the low air exchange rate (0.29 h^{-1}) between the corridor and room. However, if a transient model for air flow and particle transport between the corridor and the room is constructed using their parameters, the modeled room concentration shows a substantial response to the increase in the corridor particle concentration. A possible explanation for this

When I was a graduate student…

Ducts as sources of particles →

discrepancy is that some other pathway, such as the HVAC ductwork, duct leaks, or the ceiling plenum, was the main source of particle-bearing air infiltrating into the conference room, not the leaks between the room and the corridor. Furthermore, with the HVAC system off, it is not clear whether the room has a negative pressure with respect to the corridor, which would have to be the case in order to have air flow and particle transport between these two spaces.

McMurry et al. (1985) measured indoor/outdoor (I/O) ratios in a well-sealed residence, with no known indoor sources and found no correspondence between these ratios and particle diameter for particles between 0.1 and 1 μm. In developing their approach and analysis, they assumed that the indoor and outdoor concentrations were at steady state, even though the low air exchange rates and correspondingly long residence times in this study make steady-state conditions more difficult to achieve. The potential impact of assuming steady state when the system is transient can be seen in their data during a rainfall episode where the I/O ratios rise dramatically for all size ranges due to a sharp drop in outdoor concentrations. These I/O ratios decline rapidly once the rainfall episode has concluded and outdoor particle concentrations rebound. The changes in the I/O ratio over this period are probably influenced more by the time lag between the indoor and outdoor concentrations than by changes in the physical processes influencing indoor concentrations.

In addition to the whole house studies listed above, several studies have investigated penetration through manufactured cracks in experimental chambers. Lewis (1995) reported penetration factors ranging from 0.97 to 0.29 for particles increasing in size from 1 to 6 μm passing through a Perspex (plastic) slit 0.1 mm high and 40 mm wide with a pressure differential of 10 Pa maintained across the slit. Mosely et al. (2001) passed monodispersed particles through manufactured aluminum slits 0.508 mm high and 10 cm wide. They found penetration factors between 0.02 and 0.9 for 2 μm particles and 0.001 and 0.05 for 5 μm particles, with a strong dependence on the pressure differential across the crack.

In general, investigators conducting chamber studies have reported lower penetration rates than those performing whole house studies. The reasons for this are not entirely clear. However, it is reasonable that the penetration factor should be highly influenced by the size and geometry of the infiltration route, which has not been systematically investigated for a wide variety of houses. Liu and Nazaroff (2003) performed experiments measuring penetration factors as functions of particle size, crack height, pressure drop across the crack, and crack material. They found that the height of the crack significantly influenced the penetration factor. For example, they found that for 2 μm particles traveling through a 9.4 cm long smooth crack, essentially no particles deposited in a crack 1 mm high and nearly all particles deposited in a crack 0.25 mm high. Older homes, and other homes which are not tightly sealed, may have a significant portion of their infiltrating air entering through openings around pipes and electrical outlets, poorly sealed windows, and

other pathways with relatively large dimensions. The ASHRAE Fundamentals Handbook (ASHRAE 1997) reports that a large fraction of air infiltrating into a residence can come from large openings such as those around fireplace dampers (0 to 30%) or in the heating system (3 to 28%). When large pathways are predominant, penetration factors would be expected to be close to unity. In a home without larger openings, where most of the air enters through smaller cracks, the observed penetration rates may approach those found in chamber studies.

Separating the effects of deposition and penetration in a full-scale house is difficult. Often assumptions are made with respect to either the deposition rate or penetration factor and the resulting parameter is then used to calculate the other factor. Alternatively, both Thatcher and Layton (1995) and Vette et al. (2001) first determined the deposition rate by elevating the indoor particle concentration, measuring the particle loss rate as a function of particle size, and subtracting the exfiltration rate. The measured deposition rates were then used along with ambient indoor and outdoor measurements (with resuspension minimized) to determine the size-dependent penetration rate. Using this method, any changes in the deposition loss rate or variability in outdoor particle concentrations at "steady state" will lead to inaccuracies in the calculated penetration factor.

In the present study, we describe a methodology for specifically determining particle penetration as a function of particle size that takes into account the significant factors influencing such measurements, such as the particle size-dependent deposition rate onto indoor surfaces, time variation in air exchange rates and outdoor particle concentrations, and the potential effects of other particle loss mechanisms indoors. In contrast to many of the previous studies, we seek to understand the physics of penetration loss mechanisms using actual houses. Since both the chemical composition and physical characteristics of particles vary with size, understanding particle penetration as a function of particle size will be a critical component in testing and evaluating various health and exposure hypotheses. It is also important to understand whether particle penetration factors can be related to the leakage characteristics of houses.

EXPERIMENTAL PROTOCOL

Since both deposition and penetration losses are particle size-dependent and occur simultaneously, it is difficult to decouple the effects of these processes in a residence. In our experimental design the indoor concentration is varied over a wide range and we analyze events where deposition is the dominant loss mechanism and events where penetration losses dominate. A transient model employing a two-parameter fit is used to determine the combination of deposition rate and penetration factor that best fits the observed data.

For this study we conducted experiments in two houses, one in Clovis and the other in Richmond, California. At both sites, a typical experiment began with a short period of indoor resuspension activities followed by a 1 to 2 h period of concentration

☐ Oscillating Fan
☐ Particle Monitoring
○ Pressure Tap
☆ Gas Detection
○ HEPA Filter

Total Area = 639 h^2 (59 m^2)

Figure 1. Floor plan of the experimental house located in Richmond, California. Particle measurement equipment was located in the living room. Tracer gas concentrations were measured at locations denoted by stars, and indoor-outdoor pressure differentials were measured at the locations shown by the open circles.

decay. For some experiments at the Clovis house, a natural-gas-stove burner was also ignited to increase the indoor concentration of smaller particles. Following the concentration decay period, the buildings were then pressurized using a High Efficiency Particle Absolute (HEPA) filter mounted in a window at the locations shown in Figures 1 and 2. The HEPA filter supplies essentially particle free air (greater than 99.97% removal of 0.3 μm diameter particles) and creates a positive pressure gradient across the building shell (indoor pressure greater than outdoor) that prevents the entry of outdoor particles, causing the indoor particle concentration to decline to nearly zero. The effectiveness of the pressurization was confirmed by measuring the indoor-outdoor pressure differential across the building surfaces at various points. When the HEPA filter was then turned

indoor particle concentration rebounded. During the entire experiment, tracer gas measurements were made continuously at several locations within the building. Size-differentiated particle concentrations were measured every 3 min with particle instruments located both inside and outside the building.

The resuspension process raises indoor concentrations of particles larger than ~0.2 μm in diameter by causing particles that have been deposited or tracked onto surfaces to disperse in the indoor air. It is expected that these resuspended particles will be chemically stable in indoor air and will not undergo transformation processes. During the concentration decay period, indoor concentrations are relatively high and losses due to deposition will be large compared to gains due to particle infiltration. The deposition rates obtained during this period are stable and reproducible. During the concentration rebound period, the opposite will be true. Changes in indoor particle concentrations will be due almost exclusively to infiltrating outdoor particles and deposition losses will be small compared to infiltration. Thus we can effectively separate penetration and deposition losses. In some cases, chemical transformation can be an important confounder; we discuss this further below.

Study Locations

To explore the effect of building characteristics on deposition losses and penetration factors, we applied this method in two separate homes, each with very different construction. Experiments were performed in two houses: one in Richmond, California and a second in Clovis, California. The Richmond house is a small, older, single-story building (59 m^2) with wood clapboard siding, un-insulated walls, and double-hung wooden windows. The building is located in a relatively unsheltered location near the San Francisco Bay and is subject to winds that exhibit a significant diurnal variation in both wind speed and direction, as well as occasional high wind speeds. Figure 1 shows a floor plan of the house. All particle measurement equipment was located in the living room and two oscillating fans sitting on the floor were used to promote mixing, as shown in Figure 1. The building contained a wall heater that was not operated during these experiments.

The Clovis residence is a moderate-sized home (134 m^2) constructed in 1972. It has a stucco exterior and single-glazed aluminum frame windows. The house is single story, with standard-height ceilings (2.4 m), a forced air heating and cooling system (which was not operated during these experiments), and ceiling fans (which were operated during the experiments to promote mixing). An additional oscillating fan located approximately 1.5 m from the floor was operated in the living room to disperse tracer gas and promote mixing near the particle measurement equipment. The house is located in a residential suburb of Fresno, California, surrounded by mature trees and homes of a similar height and size. The flat terrain and high level of sheltering resulted in relatively low levels of wind loading near the building. Figure 2 shows a floor plan of this house, along with

Gas Detection
Pressure Tap

Total house area (without garage) 1440 ft² (131 m²)

GARAGE

BEDROOM #2   BEDROOM #1

KITCHEN

HALLWAY

BATHROOM

DEN

LIVING ROOM

MASTER BEDROOM
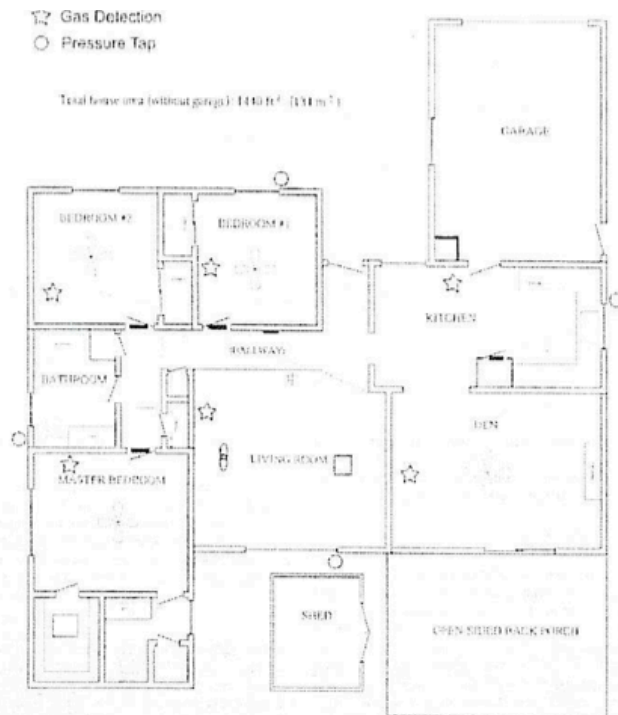
SHED

OPEN SIDED BACK PORCH

Figure 2. Floor plan of the experimental house located in Clovis, CA showing locations of ceiling fans, tracer gas measurements, and differential pressure measurements. Particle measurement equipment was located in the living room and in the outdoor shed.

Blower door measurements, in which the amount of airflow under various imposed pressure differentials is measured, are commonly used to compare the relative "air tightness" of homes (ASHRAE Standard 136 1993). These measurements can be used to calculate normalized leakage (NL), which is the leakage area normalized by floor area and a house height factor. The average house in the United States has a NL of 1.2 cm²/m² (Sherman and Matson 1997). The typical NL of a conventional new house is approximately 0.55 cm²/m² and a new well-sealed, energy-efficient house is around 0.31 cm²/m² (Sherman and Matson 2002). Older homes tend to have significantly larger NL than newer homes (Sherman and Dickerhoff 1998). The Richmond house has a normalized leakage area around 2.5 cm²/m², indicating that the structure is fairly "leaky" and that air penetrates

occurring through large penetrations in the building shell.

Measurement Equipment

The indoor particle and gas measurement instruments were located in the living room of each house. Systems to measure tracer gas concentration and pressure differentials across the building shell monitored the living room as well as several locations throughout the house, as shown in Figures 1 and 2. An additional set of particle measurement devices was also located outdoors at each house. In Richmond, the outdoor instruments were located on a table approximately 30 feet upwind of the house. In Clovis, the instruments were located in a shed adjacent to the house and samples were collected through a PM 10 inlet projecting approximately 10 feet above the shed roof.

Two aerodynamic particle counters (TSI, Model APS 3320), one located indoors and one outdoors, were used to measure size distributions for particles with aerodynamic diameters between 0.5 and 10 μm. To assure that the measurements from the two instruments were comparable, measurements with the instruments sitting side-by-side were performed before and after each test series. The comparison tests were performed both outdoors and indoors. The results were compared to determine a collection efficiency ratio between the instruments for each size bin. For a typical calibration series, the standard deviation of the collection efficiency ratio was less than 0.1 for the individual particle size bins. The efficiency ratios were used to adjust the concentrations obtained by the instruments and "match" the results. For the Clovis experiments, the matching experiments were performed with the outdoor instrument sampling through the PM 10 inlet manifold so that manifold losses would be included in the correction factor. The APS uses 52 size bins between 0.5 and 20 μm. For our analysis, the smallest size bin and all size bins over 10 μm were eliminated, because of poor correlation between instruments for the smallest size bin and the use of the PM 10 inlet outdoors reduced or eliminated particles with diameters larger than 10 μm. Data in the remaining bins were grouped to produce 12 size bins between 0.5 and 10 μm. The concentration in the largest of these bins was often very low indoors, particularly in the Clovis house with its low air exchange rates. For each size bin, we excluded periods where there were insufficient counts in the bin to provide adequate count statistics from our analysis, typically around 5 counts per measurement interval.

Two optical particle counters (Particle Measurement System, Model LAS-X), one located indoors and one outdoors, were used to measure size distributions for particles with optical diameters between 0.1 and 3 μm. The instruments were "matched" in a manner analogous to that used for the aerodynamic particle counters with similar precision in the collection efficiency ratio. The smallest and largest size bins were excluded due to difficulty in matching and a low number of counts indoors for the

size. However, the conversion from optical to aerodynamic diameter is highly dependant on particle composition and varies over time. In particular, variations in the chemical composition of the aerosol, such as high levels of carbonaceous aerosol, will lead to errors in the conversion from optical to aerodynamic diameter. As a result, we report our concentrations in terms of optical diameter for measurements performed with the optical counters. The optical diameter is not necessarily expected to be identical to the aerodynamic diameter for the particles studied.

In Clovis, CA, a substantial and highly variable fraction of the ambient aerosol can be composed of ammonium nitrate particles. These particles have been shown to dissociate into ammonia and nitric acid in the indoor environment (Lunden et al. 2003) and therefore cannot be readily modeled with a simple physical model that assumes that the particles are conserved. To determine the contribution of ammonium nitrate particles to the outdoor aerosol during these experiments, PM2.5 nitrate, carbon, and sulfate were measured with 10 min resolution using the integrated collection and vaporization method of Stolzenburg and Hering (2000). This method collects PM2.5 particulate matter by humidification and impaction onto a 1 mm diameter spot on a metal substrate. The sample is then analyzed by flash-vaporization and quantitation of the evolved vapor compounds. Nitrate concentrations are measured using low-temperature vaporization in a nitrogen carrier gas with quantitation of the evolved vapors using a chemiluminescent monitor equipped with a molybdenum converter to reduce higher oxides of nitrogen to nitric oxide. Sulfate and carbon analyses are performed using high-temperature heating, with analysis of the evolved sulfur dioxide by UV fluorescence and carbon dioxide by nondispersive infrared absorption.

Indoor and outdoor measurements were performed simultaneously using a four-cell system. One pair of cells (one indoors and one outdoors) was used for nitrate measurements. A second pair was used for the combined measurement of carbon and sulfate. The outdoor nitrate cell and outdoor sulfate-carbon cell were housed indoors inside a box that was ventilated with outdoor air to maintain near-outdoor temperature at the point of sample collection. A more detailed description of this system can be found in Lunden et al. (2003).

Air infiltration rates were measured using sulfur hexafluoride tracer gas techniques (ASHRAE 1997) with a photo-acoustic infrared detector system (Bruel and Kjaer, Model 1312). For the Richmond experiments, an injection/decay method was used. In this method, a pulse of tracer gas is injected and mixed within the space. The loss of tracer gas over time is then monitored at three to six locations and the concentration decay rate is used to determine the infiltration rate. During the Clovis experiments, a constant injection system was used. In this method, tracer gas is injected at a constant rate before and during each experiment. The time-varying infiltration rate is calculated using a transient

Blower Door

Richmond → "leaky"

When I was a graduate student…

mass balance approach that accounts for the injection rate and the time-dependent infiltration losses. In general, the calculated air exchange rate at a given time was essentially the same for each measurement location within the house, and the average concentration for all locations was used in the model. The only exception occurred when the window-mounted HEPA filter was operated in the Clovis residence. During these periods, the SF_6 concentration in the room containing the HEPA fan was very low and that measurement point was excluded from the average in order to obtain an air exchange rate more representative of the entire house.

An automated, multiple channel differential pressure system (Energy Conservatory, APT 8) was used to monitor pressure differentials across the building shell at various points for each house (see Figures 1 and 2) and to assure that pressurization with the HEPA filtration system was always positive (inside with respect to outside) on all surfaces of the building envelope.

Analysis Method

The concentration of particles indoors is a balance between the sources and sinks of particles in the indoor environment. Figure 3 illustrates potentially important factors affecting indoor concentrations. In the most general form, the indoor concentration of particles of a specific size and composition particle can be represented by the following equation:

$$\frac{\partial C_I}{\partial t} = (C_o P - C_I)\lambda_v - C_I \beta + G + S + F + K + H, \quad [1]$$

where C_I is the indoor particle concentration at time t (# cm^{-3}), t is time (h), C_o is the outdoor particle concentration at time t (# cm^{-3}), P is the penetration factor, λ_v is the air exchange rate (h^{-1}), β is the deposition loss rate (h^{-1}), G is the generation of particles indoors (# cm^{-3} h^{-1}), S is the particle formation through gas-particle conversion (# cm^{-3} h^{-1}), F is the particle formation due to chemical reaction (# cm^{-3} h^{-1}), K is the particle size change through coagulation (# cm^{-3} h^{-1}), and H is the particle size change through hygroscopic growth (# cm^{-3} h^{-1}).

For the conditions and particle size ranges used in these experiments, we do not expect coagulation (K), hygroscopic growth (H), or formation (F) to have a significant impact on indoor particle concentrations. In addition, care was taken to avoid indoor sources (G) by using an unoccupied space and operating equipment, such as pumps, that could generate particles outdoors. Therefore, we assume that these effects are negligible in our analysis. During some experiments, observations indicated that the results were complicated by dissociation and vaporization of ammonium nitrate particles (S). Periods of high ammonium nitrate were excluded from our results. For the periods selected for our analysis, we could reduce the mass balance equation to

$$\frac{\partial C_I}{\partial t} = C_o P \lambda_v - C_I(\lambda_v + \beta). \quad [2]$$

Under steady-state conditions, this equation is solved easily for a constant outdoor concentration and stable infiltration rate. However, in most real-world situations—as was the case for these experiments—there is significant time variation in C_o and
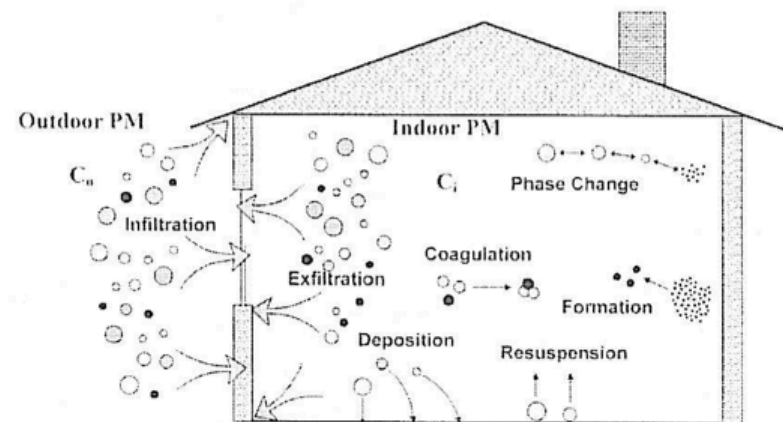
Figure 3. Schematic of particle transport, transformation, and removal processes in the indoor environment.

λ_v, causing the steady-state solution to be invalid. When $\partial C_I/\partial t$ is not zero, the equation can be solved using a basic "forward-marching" scheme with time step, Δt, as shown below:

$$C_I(t_2) = C_I(t_1) + P C_o(t_1)\lambda_v(t_1)\Delta t - C_I(t_1)(\lambda_v(t_1) + \beta)\Delta t. \quad [3]$$

In these experiments, the time step used was 3 min, corresponding to the measurement interval for the size-resolved instruments.

The equation-solving methodology employed the minimization of the sum of the square of the differences between the measured and modeled indoor concentration at each time step divided by the measured concentration at that time. Since the concentration varied over several orders of magnitude during each experiment (from a maximum after resuspension to a minimum during the filtration period), dividing by the measured concentration normalized the weighting of each point over the entire experiment. Although this leads to biases due to measurement errors, it was found to provide better fits over the entire data range than those produced by other weighting schemes. For instance, without weighting the high concentrations periods dominated and the curve fit at lower concentrations was poor, and a weighting scheme minimizing the inverse of the measured/modeled difference led to large errors at high concentrations. Individual measurements which appeared to be inaccurate due to either equipment limitations or instabilities were excluded from the analysis if they exhibited the following characteristics: (1) zero or near zero counts or (2) one or more points where counts differ by more than 50% from the counts in both the preceding and following measurements in the time series, with no physical explanation. In general, the excluded measurements represented less than 1% of the total number of points, with the exception of the largest size channel of each instrument, which exhibited very low particle counts over significant periods.

The Excel spreadsheet tool SOLVE (Microsoft Corporation, Redmond, WA) was used to determine the deposition loss rate, β, and penetration factor, P, which minimized the sum of the weighting function residuals for each particle size range. Due to bias introduced by weighting the model/measurement error by the measured concentration, the average modeled concentration tended to be slightly lower than the measured average concentration. This difference was typically less than 5%. In consideration of this bias, the goodness-of-fit was determined using two measures: the first is the measured/modeled correlation coefficient and the second is the difference between the measured and modeled average concentration. If the correlation coefficient was less than 0.95 or the difference between the average concentrations was more than 10% for a time series reconstruction for a given particle size range, then the fit was rejected and the results were discarded. Typically the model performed very well and few rejections were observed, for example, in the Richmond experiments, 12 of the 122 reconstructions were rejected, and only 3 of the 81 reconstructions were rejected in the Clovis data. One experiment performed at the Clovis house was discarded due

to problems associated with interference by ammonium nitrate, which will be discussed in more detail subsequently. For each particle size range, the deposition loss rates and penetration factors obtained from the reconstructions were averaged over all experiments performed at each home. The average and standard deviation are reported for each site.

RESULTS AND DISCUSSION

The penetration rebound method produces a characteristic indoor particle profile as shown in Figure 4 for smaller particle sizes measured with the optical particle counter and Figure 5 for larger particles measured with the aerodynamic particle counter. Immediately following resuspension, indoor concentrations are significantly higher than during the quiescent periods at the end of each experiment, for all but the smallest particle sizes. Concentrations of particles greater than 0.5 μm typically increase by more than a factor of 5, and particles larger than 3 μm increased by more than a factor of 10, compared with the quiescent background. Similarly, during the period when the house was pressurized with filtered air, indoor concentrations are significantly lower than quiescent concentrations. This large range of indoor concentrations increases the sensitivity of the method and improves the ability to find unique solutions for the penetration factor and deposition rate. However, the use of resuspended and natural gas stove-generated particles as sources of additional particle concentrations indoors may introduce error into the calculations if the properties of these particles (such as shape and density) are different than those found in ambient air. To the extent that resuspended particles represent materials originally deposited from air, they should be similar to ambient particles but lacking the most volatile or unstable components. The portion of resuspended particles originating from tracked materials may not represent the chemical composition of ambient air well, but as long as they are stable and similarly shaped the deposition behavior should be similar to that observed for ambient particles. Mechanically separated materials, such as fibers, are typically larger than 10 μm and would not be included in the measurements. Particles from natural gas combustion should be similar to those in other fresh combustion aerosols, but they may not represent other submicron particles, such as inorganic aerosols, well if the densities are significantly different.

Changes in the outdoor concentration during the experiment increase the sensitivity of the fit because deposition losses are a function of indoor concentration, and penetration losses are a function of outdoor concentrations. Consequently, outdoor concentration variability helps differentiate the effects of penetration and deposition losses. Significant changes in outdoor concentration occur over the course of one or more hours on a typical day, but they can occur more rapidly, for instance when the wind direction shifts. For particle sizes near the larger end of an instrument's range, low indoor particle counts often lead to poor count statistics and a high degree of sample-to-sample variability, especially during the rebound phase or when air exchange rates are low. This variability can lead to a decrease in
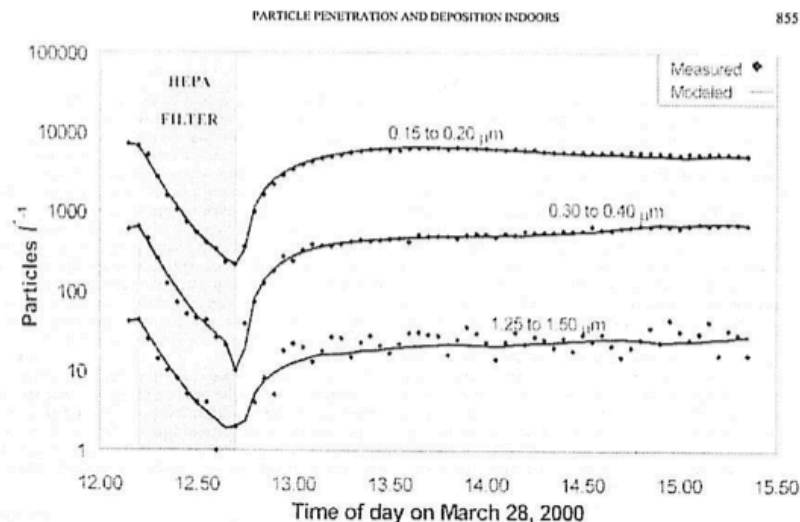
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When I was a graduate student…

Figure 4. Measured and modeled indoor particle concentrations for several optical particle diameter ranges during a typical run in Richmond, CA. The larger particle size ranges show increased sample-to-sample variability due to the low number of counts per sample period.
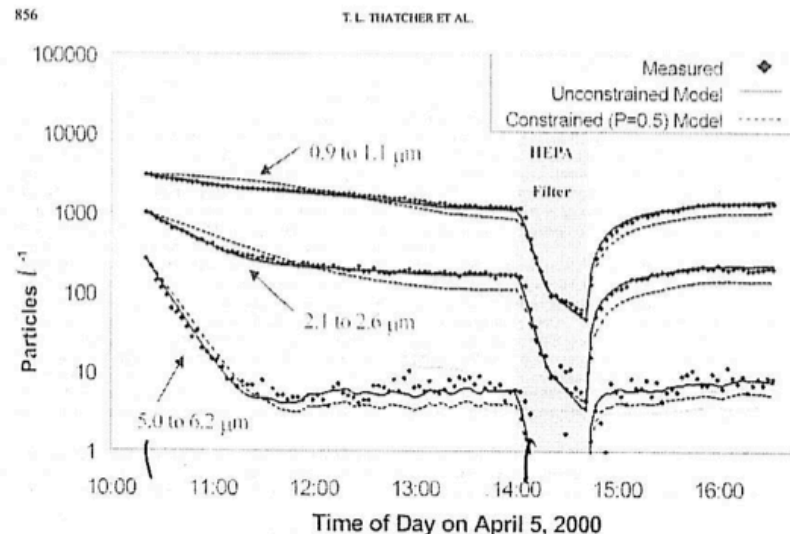
Figure 5. Measured and modeled indoor concentrations for selected aerodynamic particle diameters during a typical experiment at the Richmond site. For the constrained model, the penetration factor is fixed at 0.5 and the deposition rates are determined using the same residual minimization process as used in the unconstrained results.

the sensitivity of the fit of the model to the data. Figures 4 and 5 illustrate the data and model fit during the experiments. The model fits well on both the downward sloping deposition phase and on the upward sloping rebound phase, indicating that both deposition and penetration losses are appropriately described.

The sensitivity of the model fit to the penetration factor value can be seen in Figure 5. This example uses APS data from the Richmond experiments with the model constrained to a penetration factor arbitrarily fixed at 0.5, leaving the deposition rate as the sole fitting parameter. The fixed penetration factor results in poorer fits and reduced correlation coefficients (from 0.994 to 0.965 for 0.9–1.1 μm, from 0.996 to 0.973 for 2.1–2.6 μm, and from 0.993 to 0.988 for 5.0–6.2 μm). In this example, where the penetration factor is lower than the "best-fit" penetration factor, the solver reduces the modeled deposition rate to compensate for the artificially low penetration rate. This results in an over-prediction of the indoor concentration in the initial period just following resuspension, when deposition is the dominant loss mechanism. Later in the experiment, when indoor concentrations are lower, the effect is reversed, with the model under-predicting indoor concentrations. If the penetration factor were fixed above the "best-fit" value, the opposite would be observed. These results demonstrate that constraining the penetration rate creates a situation where it is not possible to adequately fit both the concentration decay and rebound portions of an experiment.

At the Clovis site, the effects of ammonium nitrate dissociation and vaporization indoors confounded the effects of penetration factor and deposition rate on indoor concentrations. Figures 6 and 7 illustrate this effect. As shown in Figure 6, the outdoor ammonium nitrate concentrations are low and the modeled particle concentrations match the measured particle concentrations well early in the experiment. Later, when the outdoor nitrate concentrations rise rapidly, the outdoor particle counts show a similar rise for particles in size bins between 0.3 and 1 μm, but exhibit little effect for larger or smaller particles. This suggests that outdoor ammonium nitrate particles have diameters primarily between 0.3 and 1 μm. The model predicts that indoor particle concentrations will increase substantially when the outdoor particle concentrations increase, as expected from Equations (2) and (3). However, indoor measurements of indoor particle nitrate concentration and indoor particle concentrations do not show corresponding responses. This indicates that deposition and penetration losses are not the only processes affecting the indoor particle concentrations at this site during times of high outdoor ammonium nitrate concentrations. As a consequence, a simple chemical-conservative model cannot be

used to represent adequately the indoor particle concentration during these periods. Methods used for assessing losses of particle nitrate and conversion to gaseous ammonia and nitric acid indoors are described in more detail by Lunden et al. (2003) and Fischer et al. (2003).

Determining the size distribution for ammonium nitrate and subtracting the nitrate particles from the size-resolved particle concentrations both indoors and outdoors could remove the effect of nitrate transformation. Since our time-resolved nitrate measurements are not size-resolved, this method would require a very stable nitrate size distribution. Figure 7 shows indoor and outdoor particle concentrations for selected size ranges and PM2.5 nitrate concentrations measured both outdoors and indoors during a period when no rebound experiments were conducted. Initially the outdoor PM 2.5 nitrate concentration is low and stable. Between approximately 0900 and 1200, a nitrate peak occurs outdoors. The outdoor particle size distributions for particles with diameters less than about a micron exhibit peaks during the nitrate episode. The response appears first in the 0.15 to 0.2 μm size bin and shifts to larger size ranges as the episode develops. By the time the outdoor PM 2.5 nitrate concentration reaches a maximum, the peak is seen predomi-

nantly in the 0.65 to 0.80 μm size bin. Based on the response seen in the outdoor size distribution, the average size of the PM2.5 nitrate particles appears to increase as the nitrate peak episode progresses. These sizes are consistent with the bimodal ambient nitrate distribution reported by John et al. (1990). The shifting nitrate size distribution makes it difficult to remove the outdoor ammonium nitrate particles from the size distribution, in the absence of size-resolved nitrate measurements. The indoor size distributions indicate no corresponding increase in concentration during the nitrate peak episode, suggesting that either the ammonium nitrate aerosols are dissociating very rapidly indoors or they aren't being transported across the building shell. This latter seems unlikely, as other particles in the apparent size range of the ammonium nitrate particles have penetration factors greater than ~0.8.

Due to the difficulties caused by ammonium nitrate dissociation and vaporization indoors, we chose to calculate penetration factors and deposition rates for the Clovis house using data only from those portions of the experiments where the outdoor concentrations of ammonium nitrate were low and relatively stable. Despite this constraint, ammonium nitrate may still exhibit a somewhat confounding effect on the results because overall

15

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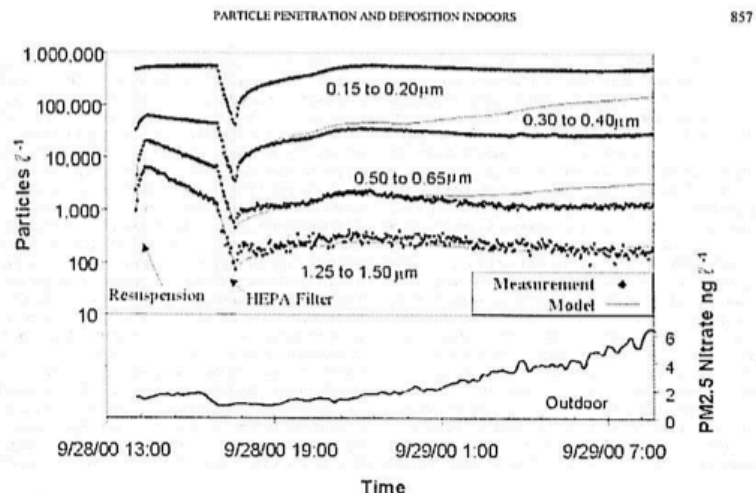
Figure 6. Measured and modeled indoor concentrations for selected optical particle diameter size ranges, along with outdoor PM2.5 nitrate concentrations at the Clovis, CA site. The increase in outdoor PM2.5 nitrate does not result in corresponding increases in indoor particle concentrations, as would be predicted by the simple physical model that assumes that particles do not undergo phase change.

Figure 7. Indoor and outdoor concentrations for PM2.5 nitrate and selected optical particle diameter size ranges. The outdoor nitrate peak results an increase in the outdoor particle concentration for particles with optical particle diameters between 0.1 and 1.0 μm but does not result in a corresponding increase in indoor concentrations.

particle concentrations were also low during these periods. This may result in artificially low penetration rate predictions for submicron particles in the Clovis experiments. Since the indoor particles during the deposition portion of the experiments consist mainly of resuspended and/or generated particles, calculated deposition rates are less likely to be affected by ammonium nitrate losses.

Table 1 lists experimental parameters for each of the experiments performed. Figure 8 illustrates how particle concentrations and conditions change over the course of an experiment. The best fit parameters and standard deviations for penetration factor and deposition loss rate at various particle sizes are listed in Table 2. Figures 9 and 10 compare the deposition loss rates and penetration factors obtained at the two sites. The optical diameter values for the Richmond site represent the best fit achieved by applying the two-parameter transient model to the data for five experiments conducted during March and April 2000. The aerodynamic data are based on only four of these experiments because the equipment failed during one of the experiments. The values for the Clovis site represent the best fit for three experiments conducted during August, September, and October 2000.

Deposition rates for the Richmond and Clovis houses are similar and fall within the range of deposition rates found by other researchers (Thatcher and Layton 1995; Fogh et al. 1997; Mosley et al. 2001). The deposition loss rates at the Clovis residence were slightly lower than those observed for the Richmond building for all particle sizes, but the differences were not statistically significant when individual points are compared. Deposition rates can vary between residences and within a single residence for many reasons. Thatcher et al. (2002) showed that both the indoor air speed (related to the internal mechanical energy) and the amount of furnishings influence deposition loss rates. In these experiments, the fans used to improve mixing indoors are expected to increase deposition rates over those that would be found in the absence of fans. Consequently, the deposition rates reported here are more representative of homes using fans or forced air heating and cooling than those without. During periods when the window-mounted HEPA filter operated, deposition may have been further enhanced in the room in which the HEPA system was located. However, the air exchange rate is high during HEPA filter operation, and the relative contribution of enhanced deposition to the overall particle loss rate is expected to be small. Moreover, the duration of the filter operation

really good Discussion
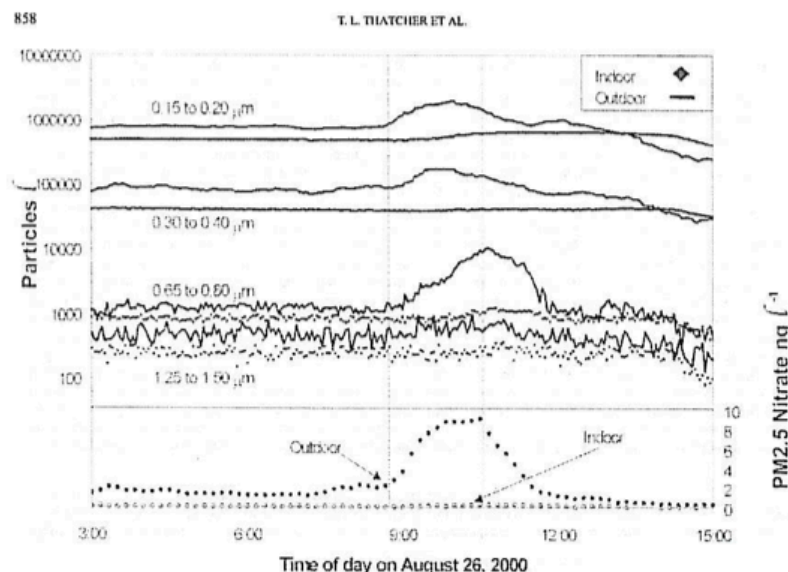
when particle concentrations are high (and thus total particle losses are potentially important) is short, approximately 15 to 20 min compared with the total time of the experiment, ca 5–6 h. Thus the possible effect of enhanced deposition due to the operation of the HEPA filter system is quite small. Both indoor air speed and furnishing level varied between the 2 homes. Mean air speed may also have varied between experiments at the same home due to changes in surface-to-air temperature differences.

Penetration factors at the Richmond house were near unity for all but the largest and smallest particle sizes. Since it is an older building with a relatively high NL area and is constructed with double hung wooden windows and wood siding, the Richmond house is presumed to have larger cracks through the building shell. Large cracks are not expected to be very efficient for removing particles (Liu and Nazaroff 2001). Penetration rates for the Clovis house were lower than those at the Richmond house, ranging from ~0.8 for particles 0.2 to 0.5 μm to just over 0.3 for particles 5 μm and larger. This may mean that in the tighter construction of the Clovis house, the penetration pathways are smaller and more effective for removing particles.

However, there are no published studies on the correlation, or lack of correlation, between NL area and average leakage crack dimensions. For particles between 0.1 and 1.0 μm there may be a confounding effect due to ammonium nitrate dissociation in the Clovis house, since ammonium nitrate particles are in this size range—see Figure 7 and John et al. (1990), even though the data sets were selected to avoid periods of high nitrate measurements. This may yield calculated penetration factors that are lower than the actual penetration factor for particles in this particular size range.

The correlation between the deposition rates calculated by the two sets of instruments (APS and LAS-X) is very good for most sizes, especially considering that the instruments measure particles in a different manner (aerodynamic and optical diameter, respectively). The standard deviations for the deposition loss rates averaged about 60% of the deposition rate value. It is not clear from this study how much of this variation is due to measurement and fitting inaccuracies and how much is due to actual variability in the deposition rate. A comparison of previous research has indicated that deposition loss rates can vary considerably based on

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Table 1

Air exchange rates and concentration bounds for selected median particle diameters particle for each experiment

Figure 8. Air exchange rate and indoor and outdoor temperature, relative humidity, pressure difference, and concentrations for selected particle sizes as a function of time over the course of a typical experiment.

conditions within the interior space (Thatcher et al. 2002). The standard deviations for the penetration factors averaged 16% of the penetration factor, and once again the portion of the variability attributable to experimental uncertainty as opposed to variations in the actual derived rate is unclear. The data and model of Liu and Nazaroff (2001, 2003) and the experiments of Mosely et al. (2001) suggest that the penetration factor is a function of pressure differential across the crack (reflecting flow rate effects

859

17

When I was a graduate student…

Table 2

Average model fit parameters and standard deviations for deposition loss rate and penetration factor at the Richmond and Clovis residences by (a) median optical diameter and (b) median aerodynamic diameter

	Median optical diameter of size range															
	0.13	0.175	0.225	0.275	0.35	0.575	0.725	0.9	1.125	1.375	1.75	2.25				
(a) Optical particle counter results																
Clovis																
Deposition loss rate (hr-1)	0.12±0.09	0.11±0.10	0.15±0.16	0.2±0.2	0.2±0.2	0.12±0.14	0.2±0.1	0.2±0.1	0.2±0.1	0.3±0.2	0.4±0.2	0.5±0.2	0			
Penetration factor	0.8±0.2	0.8±0.1	0.6±0.1	0.8±0.3	0.6±0.2	0.8±0.1	0.8±0.1	0.7±0.2	0.8±0.1	0.9±0.1	0.9±0.1	0.9±0.1	0			
Richmond																
Deposition loss rate (hr-1)	0.3±0.3	0.3±0.3	0.2±0.2	0.2±0.2	0.2±0.2	0.2±0.1	0.4±0.3	0.5±0.4	0.5±0.2	0.9±0.6	0.7±0.2	0.9±0.5	1			
Penetration factor	0.8±0.2	0.93±0.08	1.00±0.08	1.0±0.1	1.0±0.1	1.1±0.2	1.01±0.06	1.0±0.1	1.0±0.2	1.0±0.2	0.9±0.2	0.9±0.2	0.8			

	Median aerodynamic diameter of size range						
	0.65	0.81	1.0	1.2	1.5	1.9	2.4	2.9	3.6	4.5	5.6	7
(b) Aerodynamic particle counter results							
Clovis							
Deposition loss rate (hr-1)	0.1±0.1	0.1±0.1	0.1±0.1	0.2±0.1	0.3±0.1	0.5±0.1	0.9±0.1	1.3±0.4	1.8±0.4	2.2±0.8	3.3±0.6	3.5±1.1	3.
Penetration factor	0.7±0.2	0.8±0.2	0.9±0.2	0.9±0.2	0.7±0.04	0.7±0.02	0.62±0.06	0.5±0.1	0.4±0.1	0.4±0.1	0.33±0.05	0.35±0.09	0.4
Richmond							
Deposition loss rate (hr-1)	0.5±0.7	0.4±0.4	0.4±0.2	0.5±0.4	0.7±0.3	1.0±0.4	1.3±0.5	1.5±0.7	2.3±0.6	2.6±1.0	3.7±0.9	4.8±0.7
Penetration factor	1.0±0.3	1.0±0.2	1.0±0.1	0.93±0.06	0.94±0.05	0.93±0.06	0.93±0.09	0.86±0.03	0.9±0.1	0.9±0.1	0.9±0.1	0.77±0.06

*The acceptance criteria for this particle size was met for only one experiment.

861
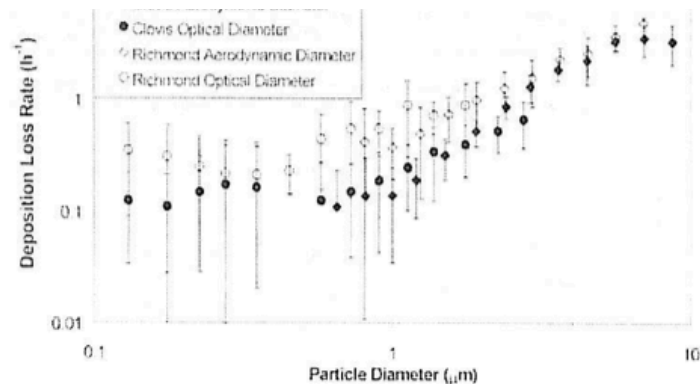
Figure 9. Averages and standard deviations of the parameter fits at the Richmond site for (a) penetration factor and (b) deposition loss rate as a function of optical and aerodynamic particle diameter. The optical and aerodynamic diameters are not necessarily identical for a given particle.
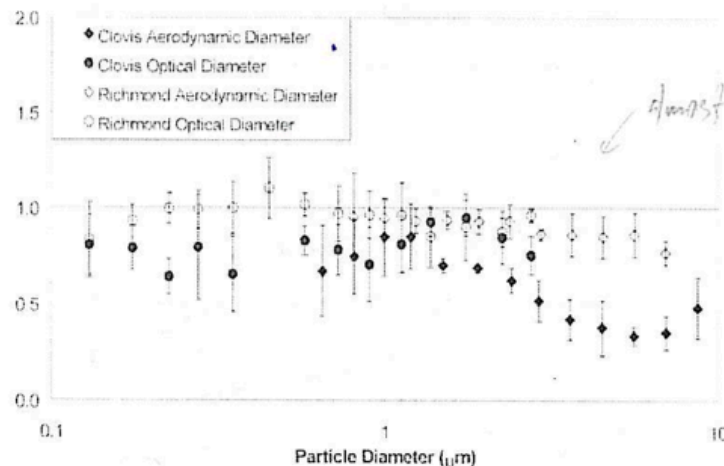
Figure 10. Averages and standard deviations of the parameter fits at the Clovis site for (a) penetration factor and (b) deposition loss rate as a function of optical and aerodynamic particle diameter. The optical and aerodynamic diameters are not necessarily identical for a given particle.

When I was a graduate student…

within the building envelope). It is not unreasonable to assume that the penetration factor in real homes will vary with environmental conditions, as these variations induce time variations in the differential pressure across the building shell. The parameter fit is not as sensitive to penetration factor as it is to deposition rate, since the decay period—which provides the best fitting data for deposition losses—is typically longer than the rebound period—which provides the best fitting data for the penetration rate, and therefore provides more data points for the model fit. Consequently, more model fit uncertainty is expected for the penetration factor. This is especially true in the upper size channels of both instruments, which sometimes record only a few particles during a measurement period, leading to noisy data and poor count statistics that reduce the accuracy of the reconstructions.

CONCLUSIONS

Deposition and penetration losses are both important factors influencing indoor particle concentrations and resulting exposures. Since these factors operate simultaneously in the indoor environment, it can be difficult to separate their effects experimentally. We have demonstrated an effective method for determining size-resolved penetration factors and deposition loss rates in full-scale homes. The two houses studied represent two distinctly different portions of the housing stock and air leakage spectrum; from a leakier, older style building with wood siding construction to a newer style building with tighter construction. Although deposition loss rates were similar for the two houses, penetration factors were significantly different. The older home had high penetration factors (near 1 for most particle sizes), while the newer home showed significant filtration by the building shell (penetration factors near 0.3 for particles larger than 5 μm). Deposition rates were slightly, but not significantly, higher in the older house. Deposition rate differences can be caused by differences in indoor air speed and/or differences in surface-to-volume ratio.

The composition of the ambient aerosol was shown to have a significant impact on the results and their interpretation as determined from some of the field experiments where ammonia nitrate concentrations were particularly large. Changes in the physical environment and gas phase contaminant concentrations indoors can lead to transformation processes, such as ammonium nitrate dissociation, which confounds the interpretation of experiments designed to quantify aerosol losses that result from crossing the building shell. Care must be taken to identify and account for the impact of these processes, in order to avoid improperly attributing their effects to deposition or penetration losses. Consideration and quantification of the various loss mechanisms must also be accounted for when estimating exposure.

The method demonstrated here permits the determination of deposition and penetration with minimal ambiguities. However, we applied the technique to only two houses. Additional work is required to obtain a better understanding of the range, variability, and particle size dependence of the penetration factor in a representative range of real homes. This information will be especially important in evaluating potential causal relationships between specific particle characteristics, such as size, and health outcomes.

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Tung, C. W., Chao, Y. H., and Burnett, J. (1999). A Methodology to Investigate the Particulate Penetration Coefficient Through Building Shell, *Atmos. Environment* 33:881–893.

Vette, A. F., Rea, A. W., Lawless, P. A., Rodes, C. E., Evans, G., Highsmith, V. R., and Sheldon, L. (2001). Characterization of Indoor-Outdoor Aerosol Concentration Relationships During the Fresno PM Exposure Studies, *Aerosol Sci. Technol.* 34:118–126.

Wallace, L. (1996). Indoor Particles: A Review. *J. Air & Waste Management Assoc.* 46:98–126.

Xu, M. D., Nematollahi, M., Sextro, R. G., Gadgil, A. J., and Nazaroff, W. W. (1994). Deposition of Tobacco Smoke Particles in a Low Ventilation Room, *Aerosol Sci. Technol.* 20:194–206.

When I was a graduate student…

Penetration of ambient submicron particles into single-family residences and associations with building characteristics

Abstract This work improves knowledge of particle penetration into buildings by (i) refining a particle penetration test method that minimizes the duration and invasiveness required by individual tests without sacrificing accuracy, (ii) applying the method in an unoccupied manufactured test house and 18 single-family homes in Austin, Texas, USA, and (iii) exploring correlations between particle penetration and building characteristics, including results from blower door air leakage tests. The mean ($\pm$ s.d.) measured penetration factor of submicron particles (20–1000 nm, not size-resolved) was 0.47 ± 0.15 in 19 residences that relied on infiltration for ventilation air, ranging from 0.17 ± 0.03 to 0.72 ± 0.08. Particle penetration factors (P) and outdoor particle source terms ($P \times$ air exchange rates) were both significantly and positively correlated with results from blower door air leakage tests. Outdoor particle source terms were also significantly and negatively correlated with the year of construction. These results suggest that occupants of leakier and older homes are exposed to higher indoor concentrations of outdoor submicron particles than those in tighter and newer homes, and that simple air leakage tests may be able to provide an approximate prediction of outdoor particle infiltration into single-family residences.

B. Stephens, J. A. Siegel

Department of Civil, Architectural and Environmental Engineering, The University of Texas at Austin, Austin, TX, USA

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Tel.: (512) 471-2410
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e-mail: stephens.brent@utexas.edu
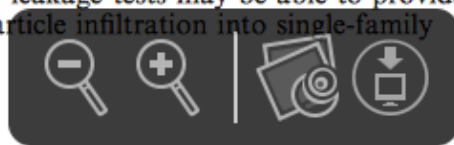
20

When I was a graduate student…
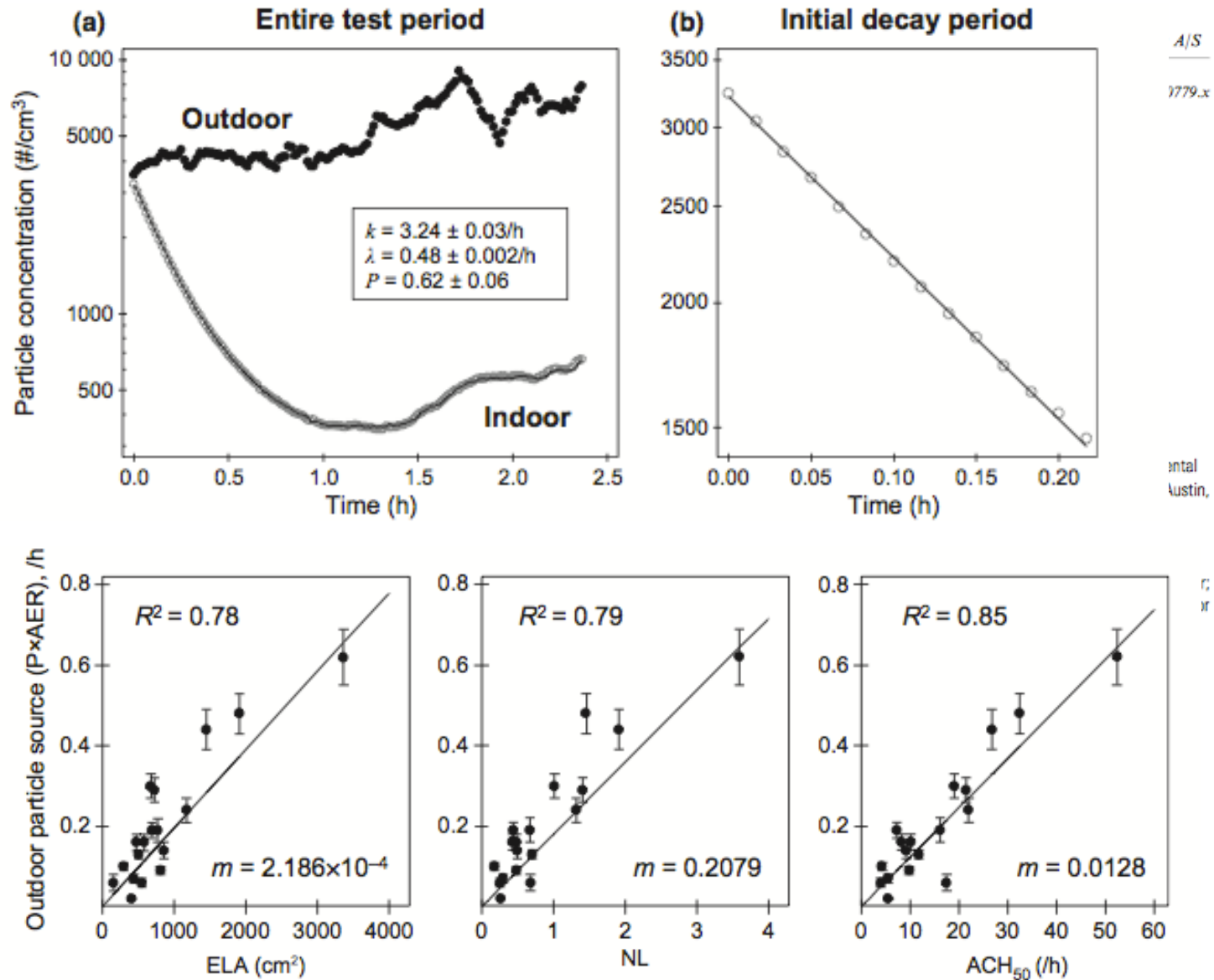
Moving from reading to *writing*

When one of my favorite authors, Hunter S. Thompson, was about 21 years old, he "used a typewriter to copy F. Scott Fitzgerald's *The Great Gatsby* and Ernest Hemingway's *A Farewell to Arms* in order to learn about the writing styles of the authors"

When I was a graduate student, I copied this idea and fully translated a paper by colleagues that I admire on a subject relevant to what I was working on:

ELSEVIER

Atmospheric Environment 38 (2004) 405–413
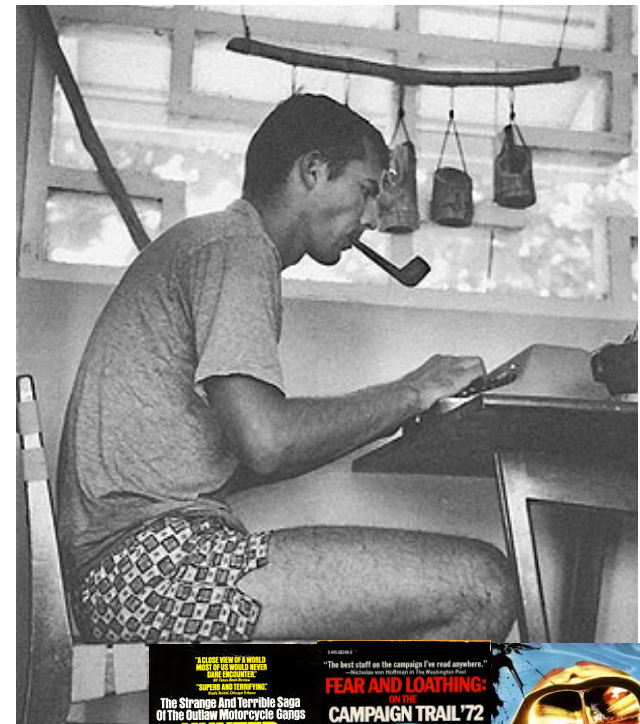
ATMOSPHERIC ENVIRONMENT

www.elsevier.com/locate/atmosenv

Effect of central fans and in-duct filters on deposition rates of ultrafine and fine particles in an occupied townhouse

Lance A. Wallace[a],*, Steven J. Emmerich[b], Cynthia Howard-Reed[b]

[a] US Environmental Protection Agency, 11568 Woodhollow Court, Reston VA 20191, USA
[b] National Institute of Standards and Technology, Gaithersburg MD 20899, USA

Moving from reading to *writing*

Abstract

Airborn
particles o
by the use
particles i
precipitat(
ranging fr
litter) wer(
cases, dep
theory. The use of the central
on the order of 0.1–0.5 h^{-1}. Tl
ineffective for particles in the
sizes. However, the ESP lost (
reduction of particle levels by
of fans and filters reduces par...
alternative approach of reducing ventilation by closing wil
use of an air filter may be an effective method of reducin

1. Introduction

The rate at wl
is an importal
exposure to air
of many factor:
acteristics, roon
flow. In many h
ing (HAC) syst

2. Methods and material

All measurements we
(July 1999–June 2001) ir
town house has been
publications (Wallace e
ward-Reed, 2002). Briefl
three stories (basement,
with a volume of about 4
by natural gas; the air
central fan circulates h
treated air through duct
conditioned area. The
recirculated air. During
house was occupied by t

3. Results

About 4640 hourly air change values were obtained during 2000. The mean (SD) air change rate was 0.64 (0.56) h^{-1}. Most of these measurements (3460) had relative standard deviations (RSD) < 15% over all eight of the conditioned rooms.

The efficiency of the ESP varied considerably depending on the time since the last cleaning of the wires and plates (Fig. 2). Efficiencies exceeded 90% for fine particles and 99% for coarse particles soon after cleaning, but began dropping below 90% after several hundred hours of operation for the fine particles and after a few hundred hours more for the coarse particles. We believe that these efficiencies are not much affected by leakage or bypass around the filter, since efficiencies for the coarse particles were 99% for many hours after cleaning. By contrast, the efficiency of the MECH filter remained near zero for fine particles (Fig. 3). For coarse particles, the efficiency increased as the filter dustcake built up. A more detailed discussion of the efficiencies of these filters is found in Emmerich and Nabinger (2001).

Moving from reading to *writing*

Abstract

Airborn
particles o

1. Introduction

The rate at wh

2. Methods and material

All measurements we

3. Results

About 4640 hourly air change values were obtained

4. Discussion

The shape of the curves in Fig. 5 is roughly as predicted by theory (Lai and Nazaroff, 2000). Deposition rates are high ($>3\,h^{-1}$) for the smallest particles due to diffusion and for the largest particles due to gravitational settling. A minimum rate between 0.1 and 0.3 µm, depending largely on the average velocity of indoor air, is predicted by theory (Lai and Nazaroff, 2000) and is consistent with the observed minimums at about 0.11–0.13 µm. However, the measured deposition rates for the case with the fan off are about an order of magnitude higher than predicted by theory for smooth surfaces. Since much of the basement was carpeted, and other floors included a number of rugs, deposition rates would be expected to be higher than predicted for smooth surfaces, but this seems unlikely to account for an order of magnitude increase. Also, this effect would be reduced for the largest particles, for which gravitational settling is dominant.

5. Conclusions

This study confirms and extends the findings of Howard-Reed et al. that (1) use of a central forced-air fan can by itself reduce particle levels in a home and (2) use of an in-duct filter can reduce these levels still further. The ESP was shown to be more effective than the MECH, particularly for fine particles, although attention needs to be paid to proper cleaning frequency. This study presents some of the first measurements of deposition rates for ultrafine particles as a function of use of the central fan and various filters. These rates can be quite high, particularly for the smallest ultrafine particles. The very strong effect of the ESP, and to a lesser degree, of the MECH, on particle decay rates suggests that use of these or other high-efficiency filters (with proper maintenance) could provide a dramatic lowering of indoor particle concentrations, whether the particle source is indoors or outdoors.

Moving from reading to *writing*

What makes a paper?

Introduction
- 3 paragraphs (about 12 citations)

Methods
- 13 paragraphs (few citations)
- Equations if necessary

Results
- 4 paragraph, 5 figures, 1 table

Discussion
- 7 paragraphs (several citations)
- Another figure and table for relevance

Conclusions
- 1 paragraph

Acknowledgements

References

Total: 25-30 paragraphs

Technical writing: Choosing a journal for your work

- You should pick a journal that has aims and scope that fit your work
  - A good place to look is the references in your own paper
    - Whatever journal is cited most might tell you where you should target
  - Also be honest about the quality and potential impact of your paper
    - Can be tough to do
  - Then look up author guidelines and see if you can start to manipulate your document into their formats

- Typically:
  - Abstract, Intro, Background (sometimes), Methods, Results, Discussion, Conclusion (sometimes), References, and any Supplementary Information (published online only)
  - 4000 to 8000 words depending on the journal (varies)

Reference management: HUGE time saver

- One of the biggest time savers you can utilize is to use a citation/reference manager

- I use Zotero and keep all of my papers in PDF form downloaded into a single 'articles' folder
  - Saved as: *Author et al 2013 – Journal – Title.pdf*
  - You can download CSL files that govern the citation format used by the journal you are targeting (swappable)

- Others use Mendeley, Endnote, and others

Reference management: HUGE time saver

Dear faculty:

If your graduate students are working on any project involving a bibliography or collecting/organizing secondary research articles, please let them know that the Galvin Library is offering workshops on an easy-to-learn citation management tool, Zotero.

Our next planned workshop dates are March 29 and April 11 from 3–4PM, but we are also available to meet with students individually outside of these times. Here is a link to the RSVP form: https://goo.gl/forms/xXNYwV37u7Vim6e63

Faculty and staff are also welcome to attend these workshops. No experience is necessary and the content is intended for beginners. If you're already using a citation manager and have specific questions about how it might work better for your work, please let me know if you'd like to set up a time to meet!

Best,

Andrea

--
Andrea Jakubas
Research & Instruction Librarian
Paul V. Galvin Library | Illinois Institute of Technology
35 W. 33rd Street, Chicago, IL 60616
ajakubas@iit.edu | P: (312) 567-3373

Driving Innovation Through Knowledge and Scholarship

Other writing time savers

- Write while you work:
  - The best time to write your methods section is when you are performing your methods
  - When you begin collecting data, begin thinking about how to tell your story

- Your introduction and background should also already be written in some form before you even start your work

- Think of the way you will present your final tables/graphs, as the majority of your actual work will go to making these
  - Or more accurately, collecting data to make them

Critical reading/writing class activity

- Each student will be assigned a paper in your neighbor's field of research

- You will have 5 minutes to summarize the work in your own words

- You should also count the number of paragraphs in each section of the paper

EFFECTIVE DATA DISPLAY

How to think critically about how to show your data

https://twitter.com/R_Thaler/status/903341857530314752/photo/1
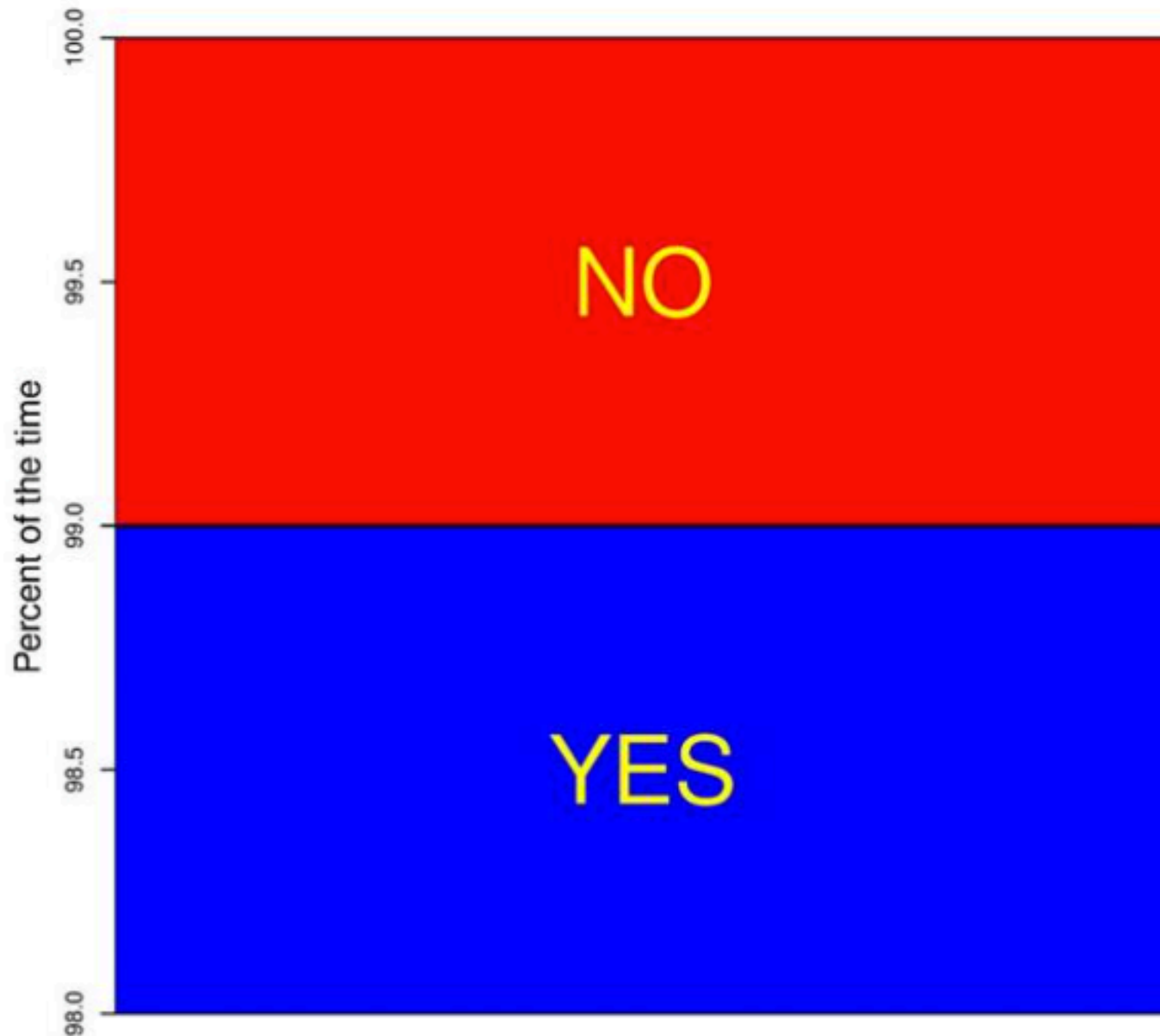
Guiding principles for graphical excellence

- Graphical excellence is the well-designed presentation of interesting data – a matter of *substance, statistics,* and *design*

- Graphical excellence consists of complex ideas communicated with clarity, precision, and efficiency

- Graphical excellence is that which gives to the viewer the greatest number of ideas in the shortest time with the least ink in the smallest space

Tufte, *The Visual Display of Quantitative Information*
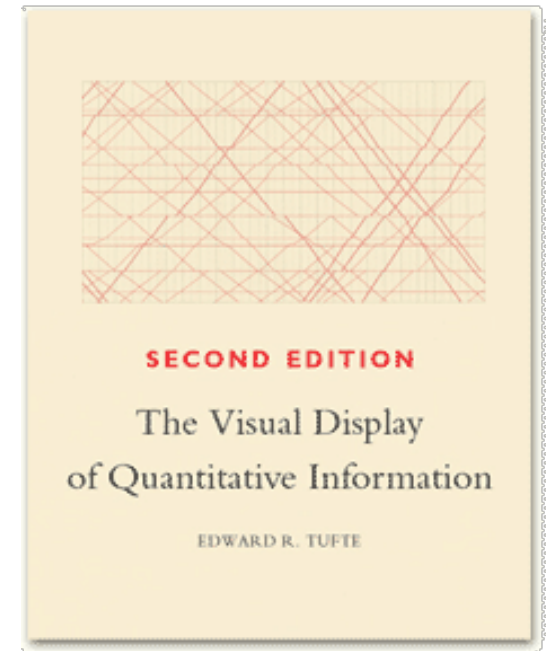
Perhaps the most famous infographic
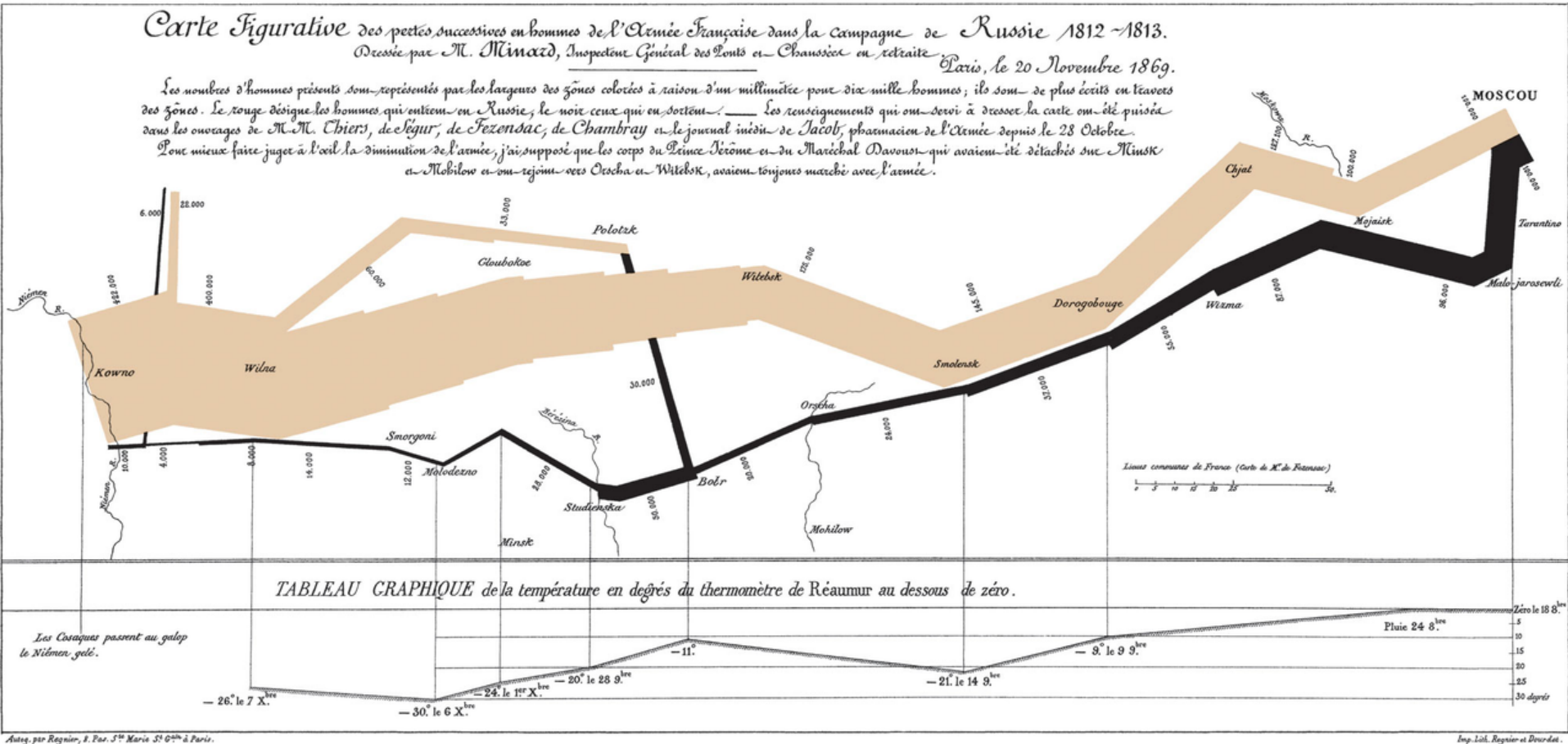
Charles Minard's 1869 chart showing the number of men in Napoleon's failed 1812 Russian invasion, their movements, as well as the temperature they encountered on the return path

Shows space, time, and magnitude of 2 variables

1854 London cholera outbreak, Dr. John Snow

O = Contaminated pump

Charles Joseph Minard, *Tableaux Gra-phiques et Cartes Figuratives de M. Minard, 1845–1869*, a portfolio of his work held by the Bibliothèque de l'École Nationale des Ponts et Chaussées, Paris.

More C. Minard: Map of French exports (space and magnitude)

Flow diagrams are still used today

Diagram 1. Energy Flow, 2007
(Quadrillion Btu)
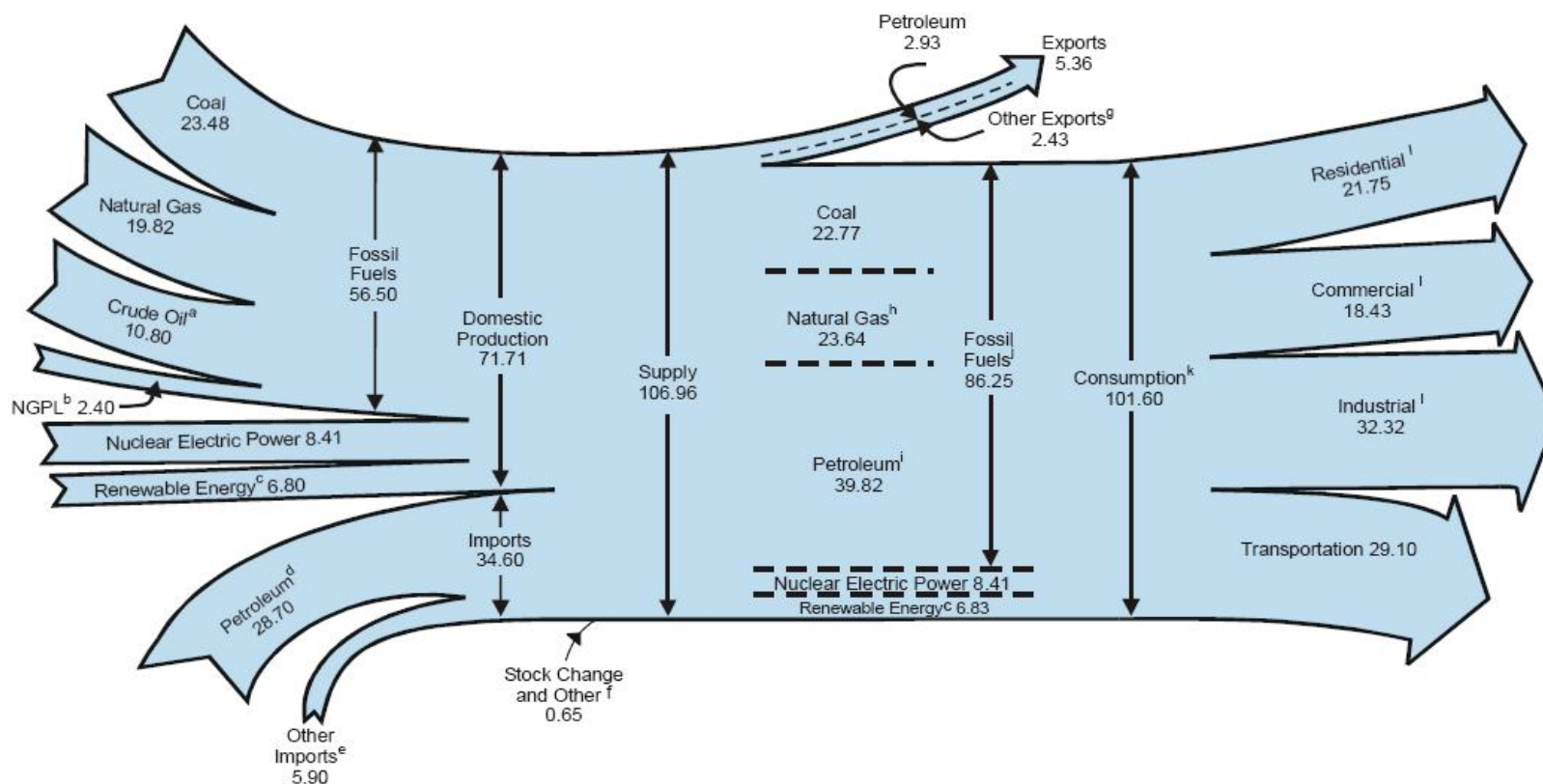
[a] Includes lease condensate.

[b] Natural gas plant liquids.

[c] Conventional hydroelectric power, biomass, geothermal, solar/photovoltaic, and wind.

[d] Crude oil and petroleum products. Includes imports into the Strategic Petroleum Reserve.

[e] Natural gas, coal, coal coke, fuel ethanol, and electricity.

[f] Adjustments, losses, and unaccounted for.

[g] Coal, natural gas, coal coke, and electricity.

[h] Natural gas only; excludes supplemental gaseous fuels.

[i] Petroleum products, including natural gas plant liquids, and crude oil burned as fuel.

[j] Includes 0.03 quadrillion Btu of coal coke net imports.

[k] Includes 0.11 quadrillion Btu of electricity net imports.

[l] Primary consumption, electricity retail sales, and electrical system energy losses, which are allocated to the end-use sectors in proportion to each sector's share of total electricity retail sales. See Note, "Electrical Systems Energy Losses," at end of Section 2.

Notes: • Data are preliminary. • Values are derived from source data prior to rounding for publication. • Totals may not equal sum of components due to independent rounding.
Sources: Tables 1.1, 1.2, 1.3, 1.4, and 2.1a.

Flow diagrams are still used today
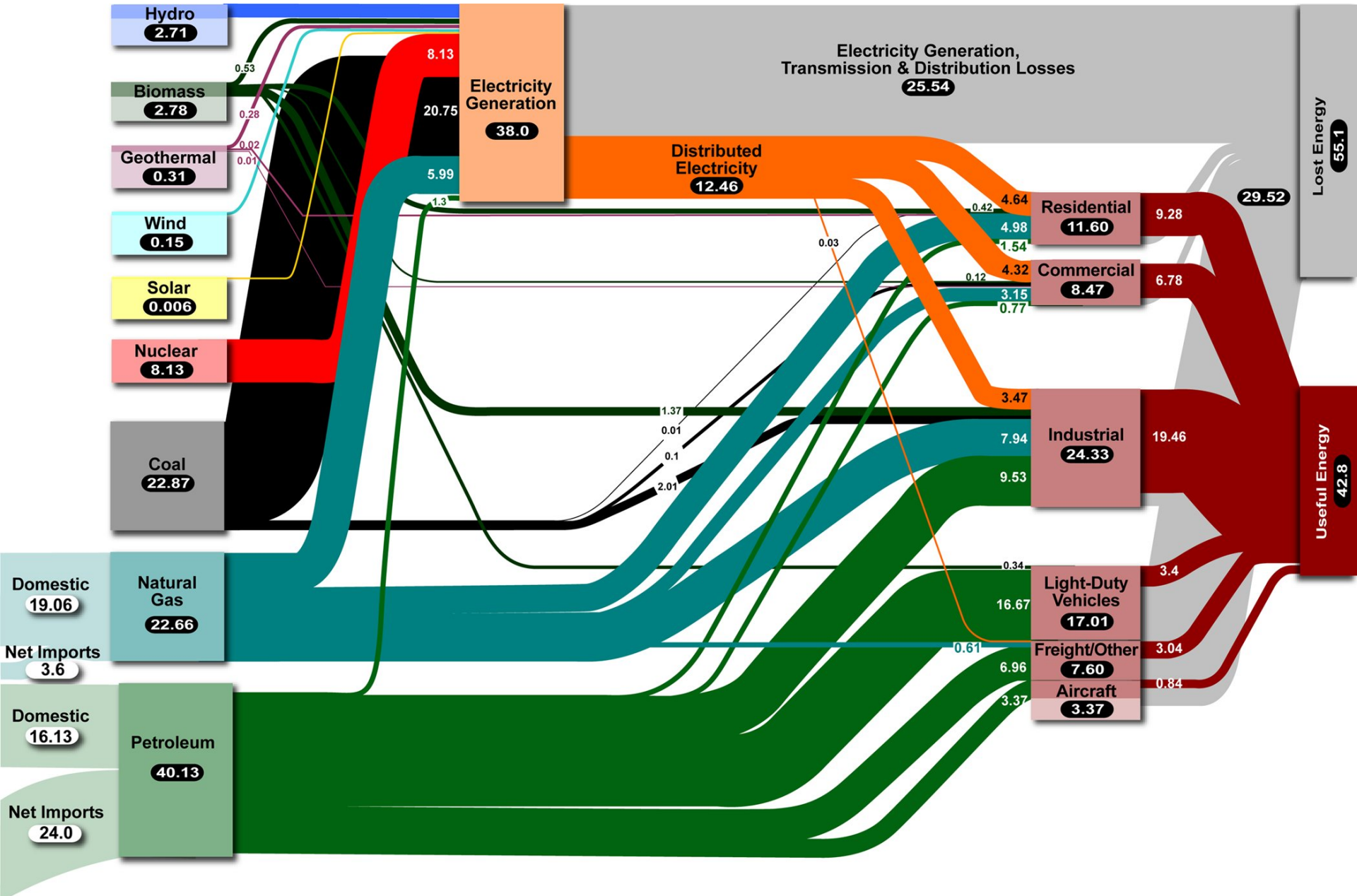
Florence Nightingale (1858)
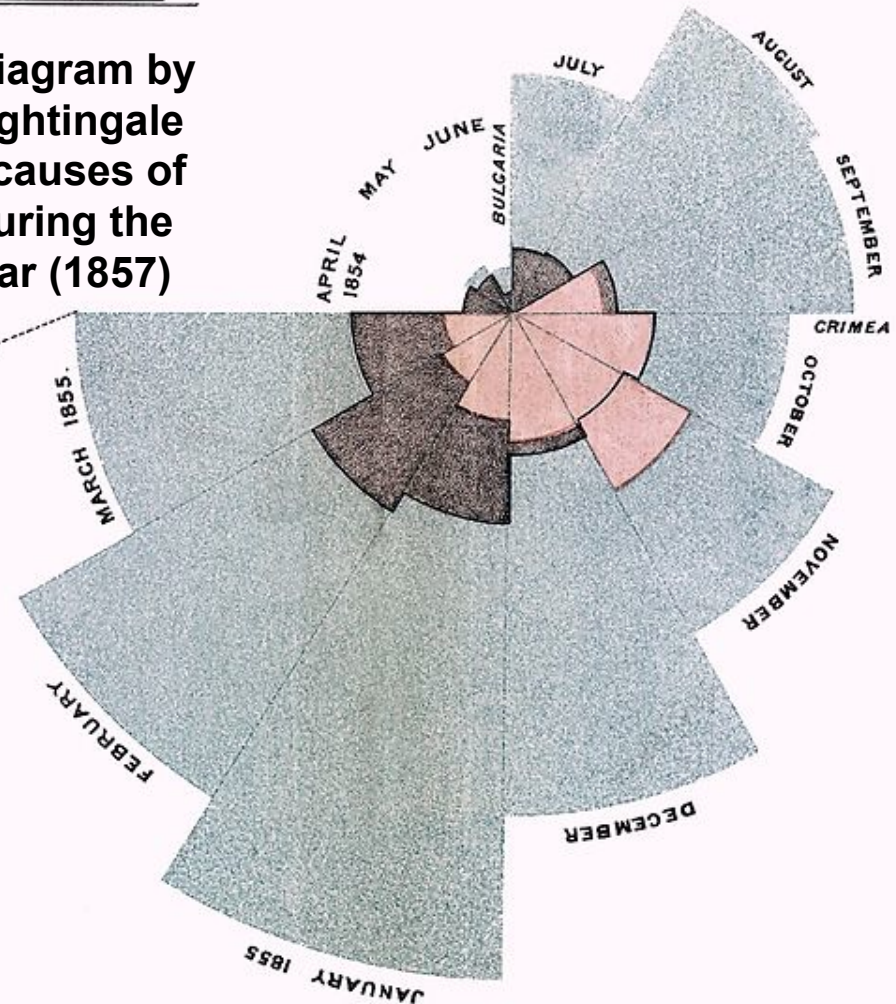
Polar area diagram by Florence Nightingale illustrating causes of mortality during the Crimean War (1857)

Modern day: Gapminder and *The Joy of Stats*

http://www.gapminder.org   https://www.youtube.com/watch?v=jbkSRLYSojo
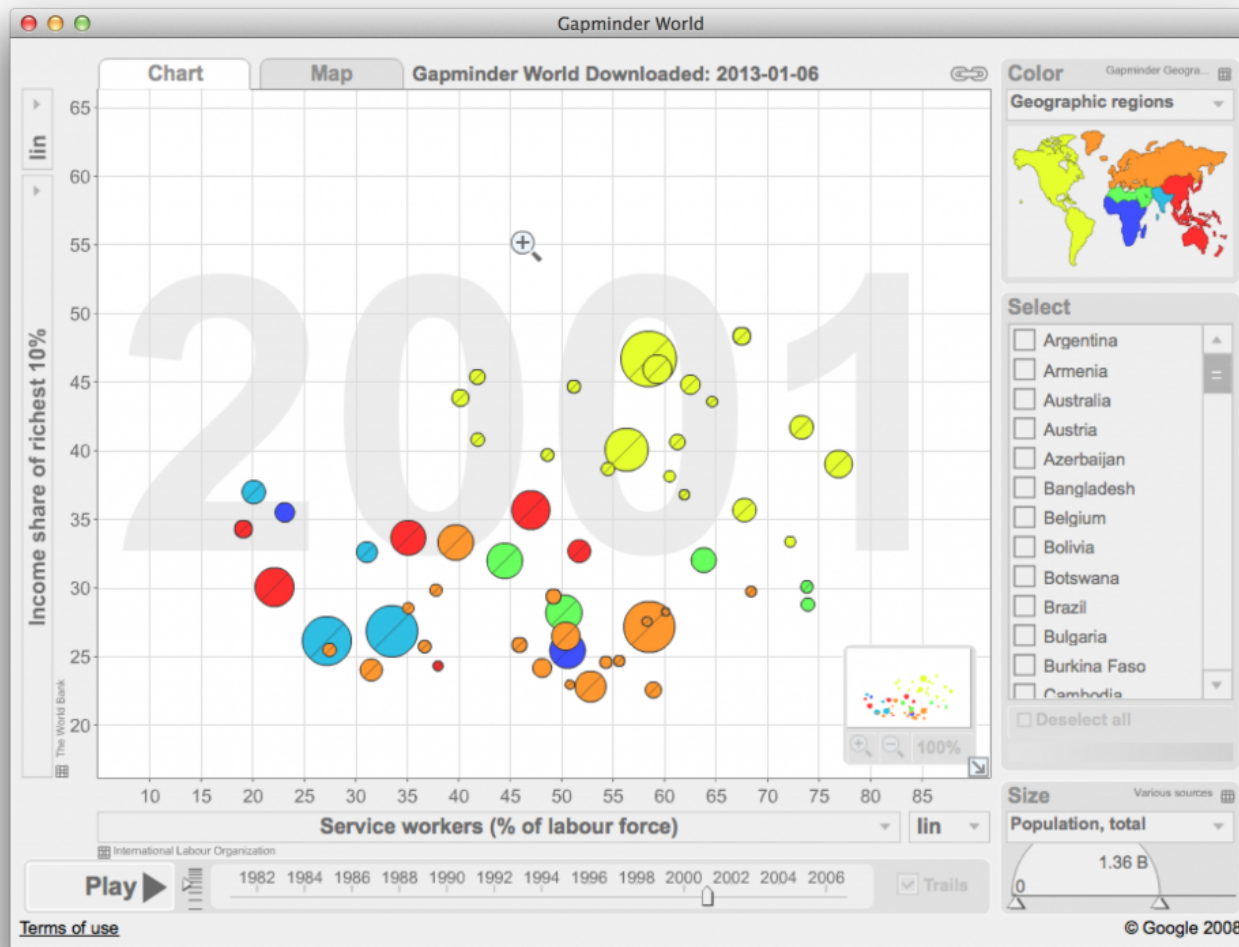
Modern day: Genealogy of rock music

http://www.math.yorku.ca/SCS/Gallery/images/timelines/Rock_and_Roll_History_1500px.jpg

http://www.math.yorku.ca/SCS/Gallery/images/timelines/Rock_and_Roll_History_1500px.jpg
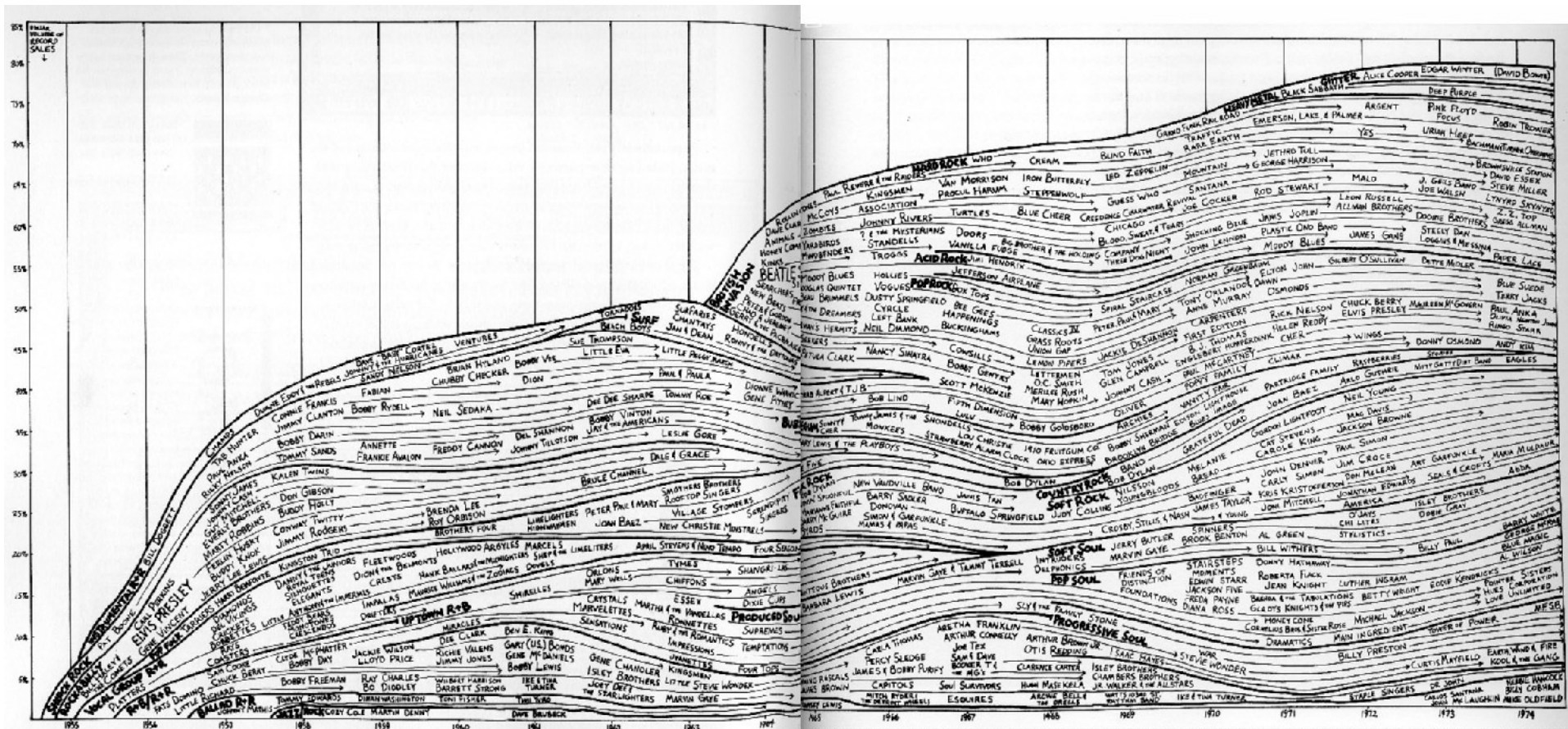
Deciding how to show information for engineering

- In what context would you like to show your data?
  - Temporal (time) variations?
  - Spatial (space) variations?
  - Statistical distributions?
  - Summary statistics?
    - Means, medians, max, min, percentiles?

- Are tables an appropriate option?

- What plot types are available?

Some available plot types
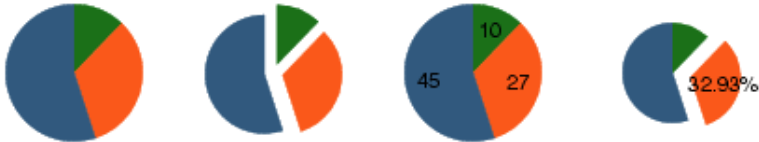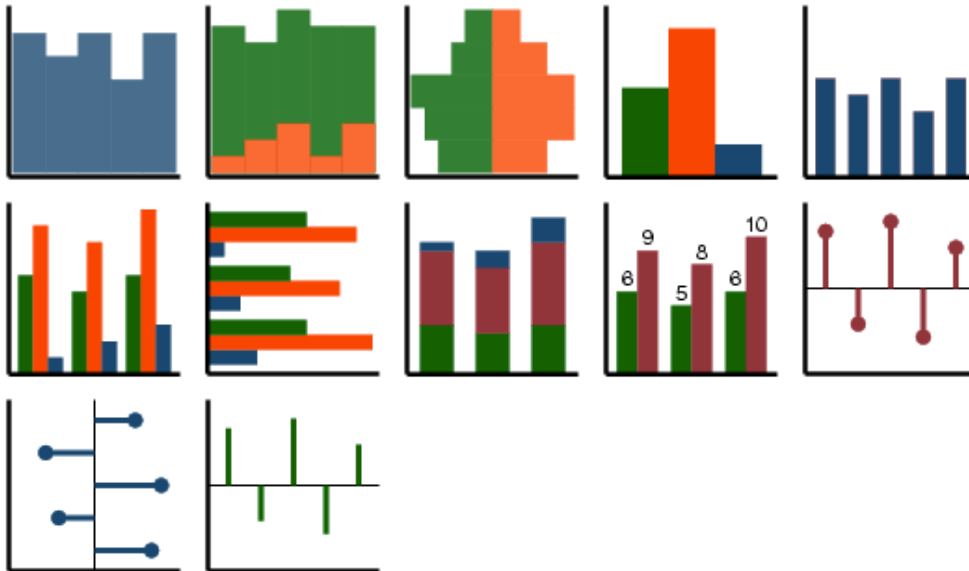
Pie charts

Bar and dropped-line charts

All plot types can be used …and abused!

http://flowingdata.com/category/visualization/ugly-visualization/

Some available plot types

Pie charts

Bar and dropped-line charts

All plot types can be used …and abused!

http://flowingdata.com/category/visualization/ugly-visualization/
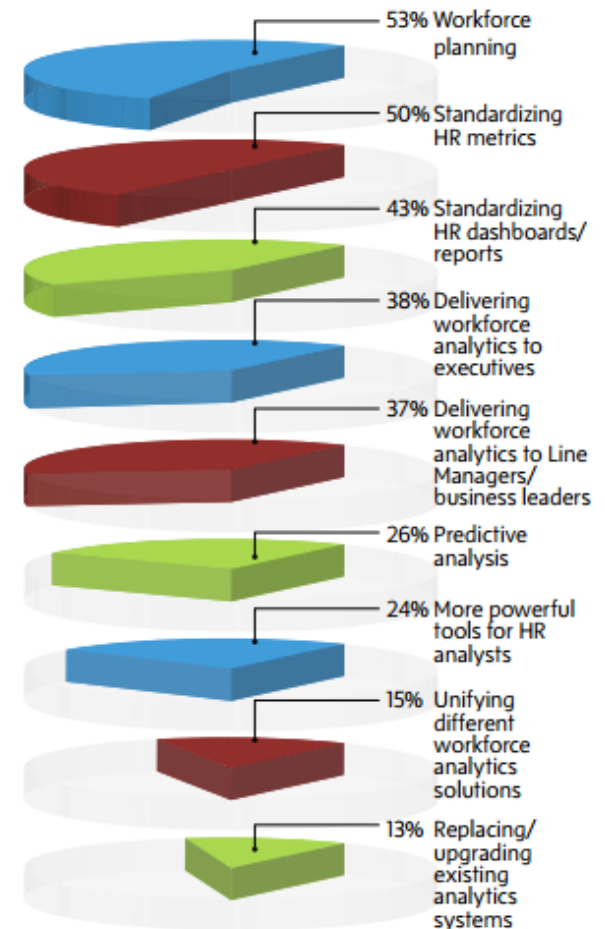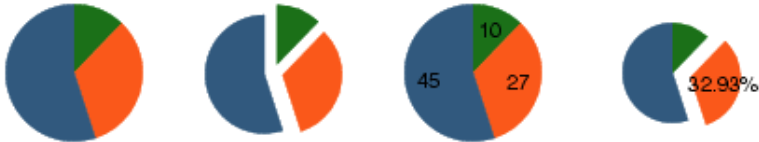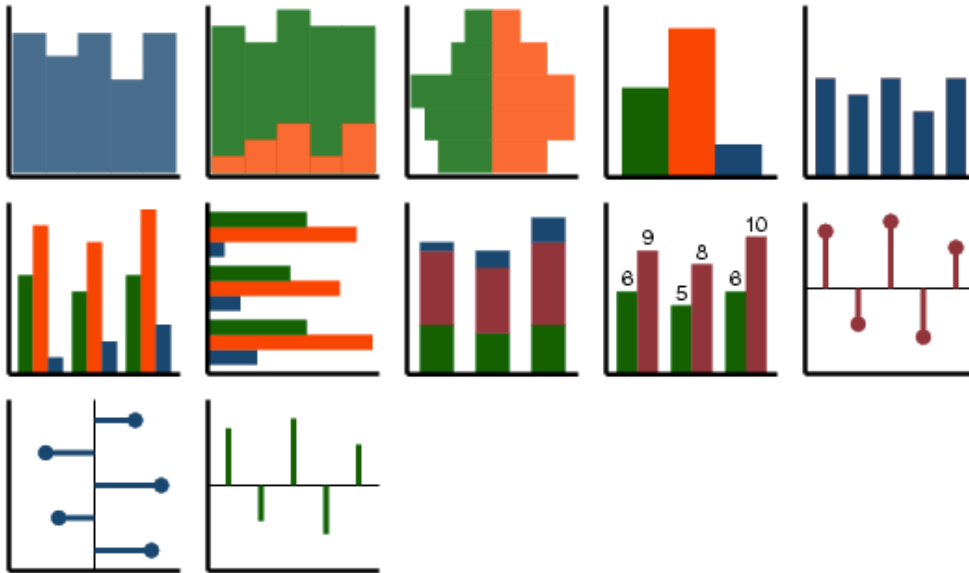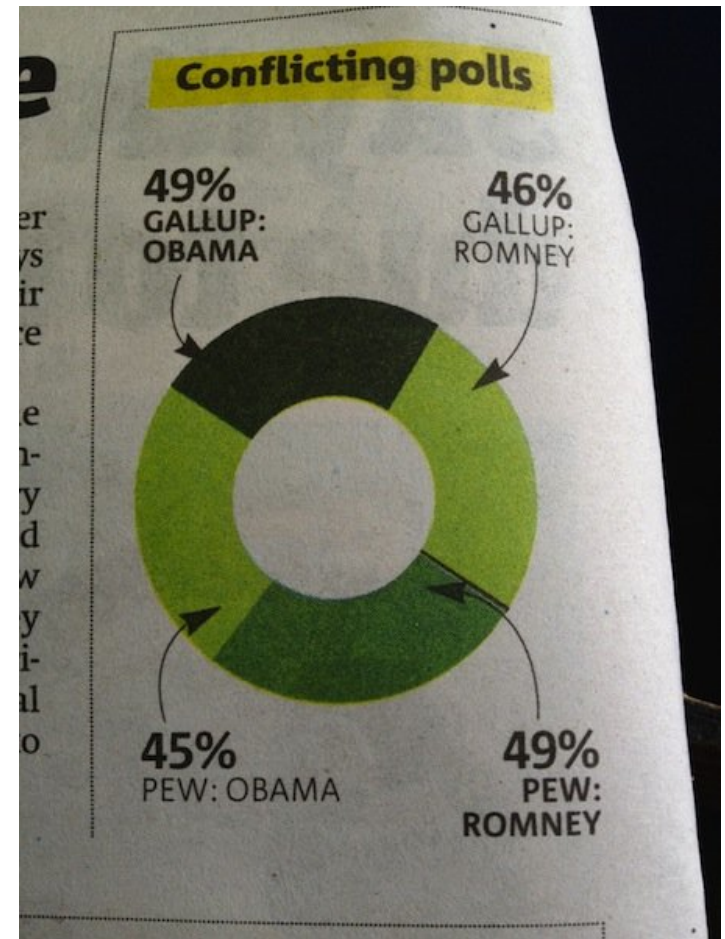
Some available plot types

Pie charts

All plot types can be used …and abused!

http://flowingdata.com/category/visualization/ugly-visualization/
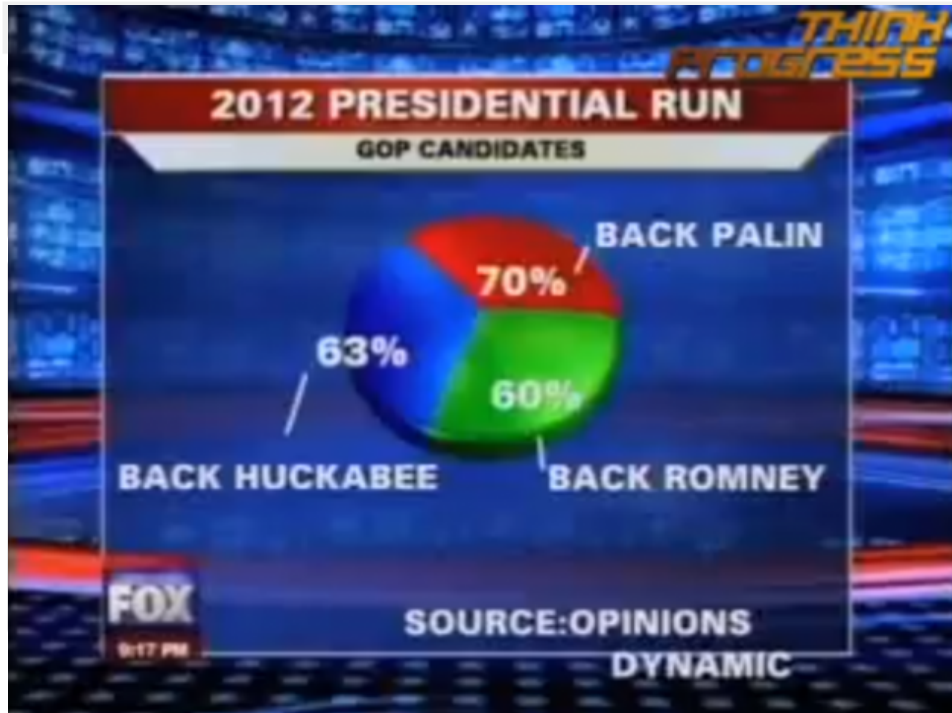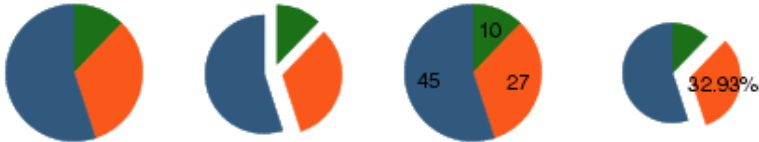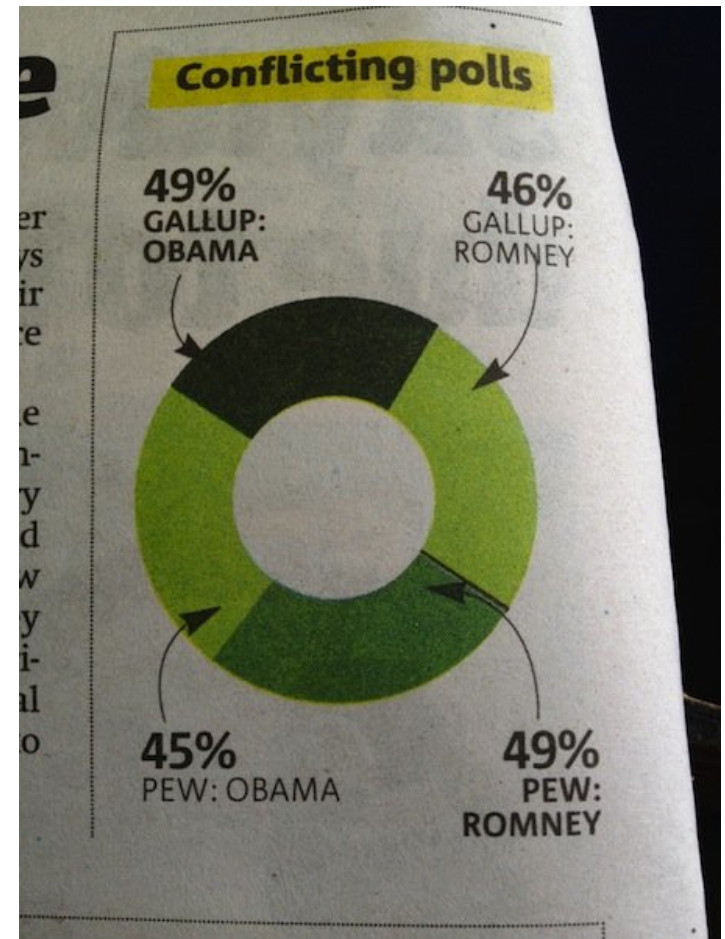
Generally speaking, which of the following toppings do you like on a pizza? Select as many as you like

42% Sweetcorn

60% Peppers

49% Bacon

56% Pepperoni

26% Spinach

33% Olives

51% Tomato (as a topping)

42% Pineapple

61% Ham

65% Mushrooms
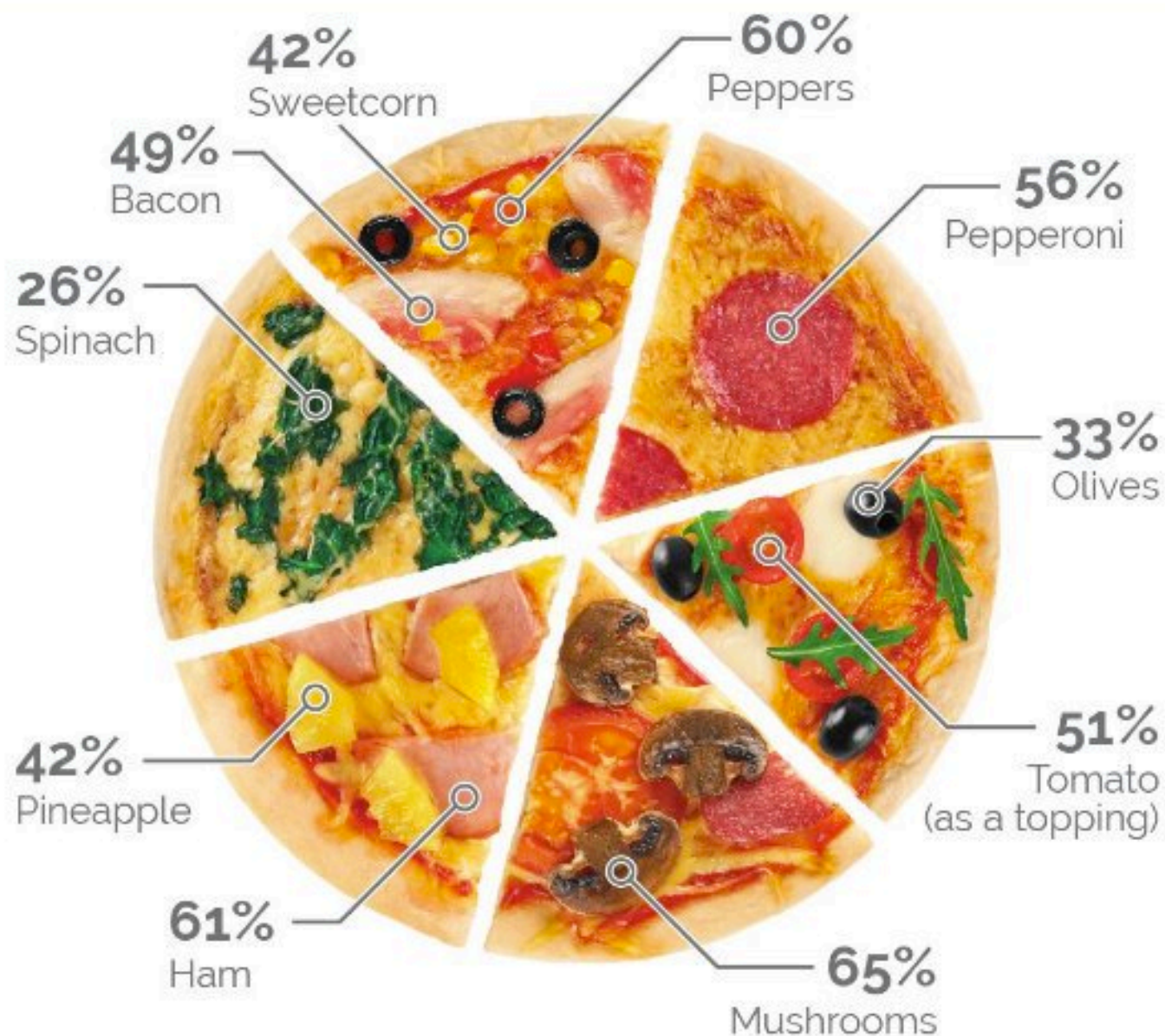
Other items not depicted include: onions (62%), chicken (56%), beef (36%), chillies (31%), jalapeños (30%), pork (25%), tuna (22%), anchovies (18%). 2% of people say they only like Margherita pizzas

Some available plot types
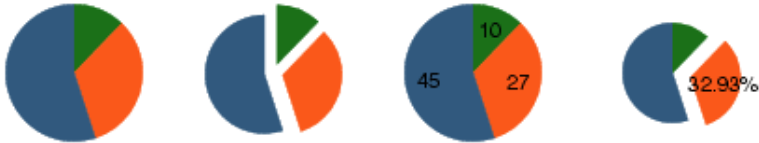
Pie charts

Bar and dropped-line charts

All plot types can be used …and abused!

http://flowingdata.com/category/visualization/ugly-visualization/

Some available plot types

http://www.biostat.wisc.edu/~kbroman/topten_worstgraphs/

Some available plot types Used and abused

Scatter and line plots
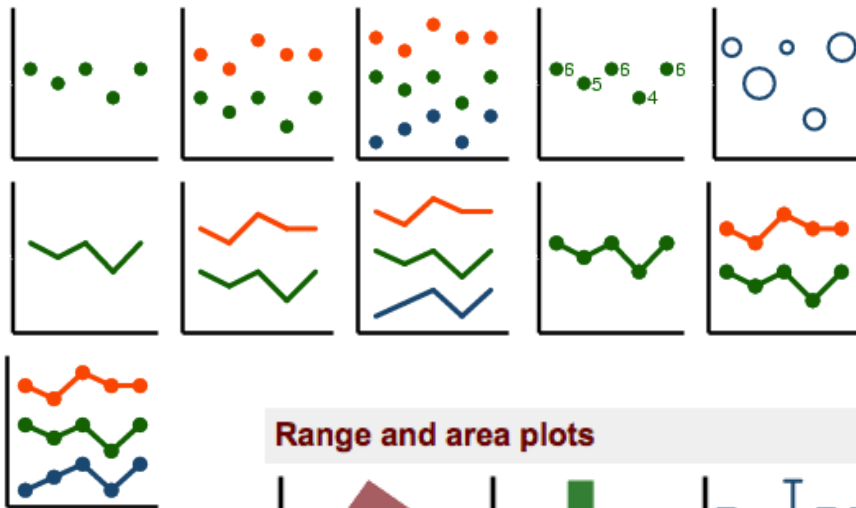
Range and area plots
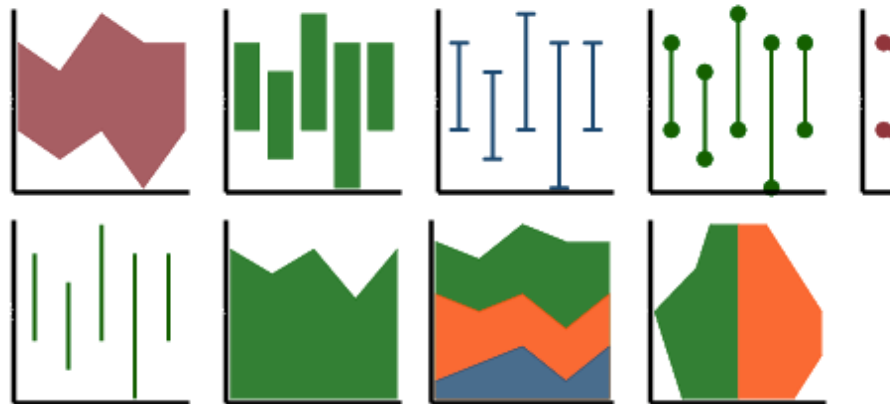
VAR and VEC
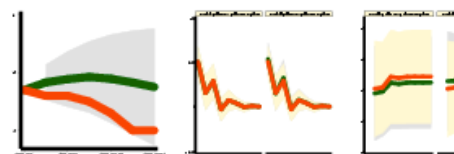
A BINNED FREQUENCY DATA – D4S139
CHINESE, JAPANESE, KOREAN & VIETNAMESE

CHI   JAP   KOR   VIE
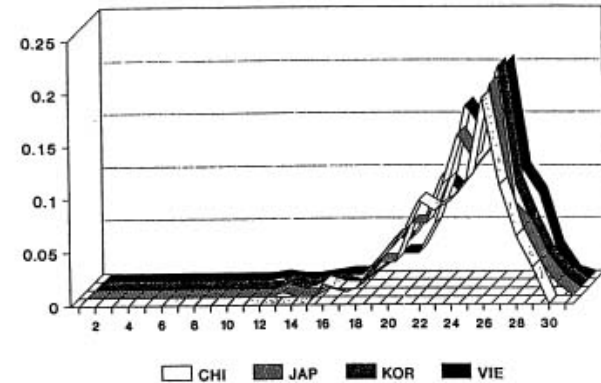
B BINNED FREQUENCY DATA – D10S28
CHINESE, JAPANESE, KOREAN, VIETNAMESE
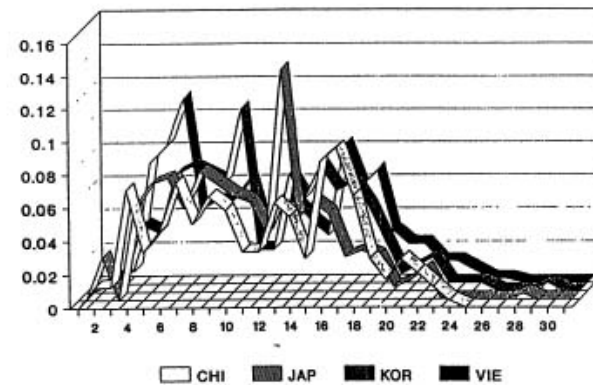
CHI   JAP   KOR   VIE

FIG. 4. *Fixed bin distribution (histogram) for two loci and four Asian subpopulations (used with permission from John Hartmann): the boundaries of the 30 bins (vertical axis) are determined by the FBI; these bins are not of equal length. Sample sizes (numbers of individuals) for Chinese, Japanese, Korean and Vietnamese are 103, 125, 93 and 215 for D4S139 and 120, 137, 100 and 193 for D10S28. The horizontal axis is the bin number; bins are not of equal length.*

http://www.biostat.wisc.edu/~kbroman/topten_worstgraphs/

types **Used and abused**
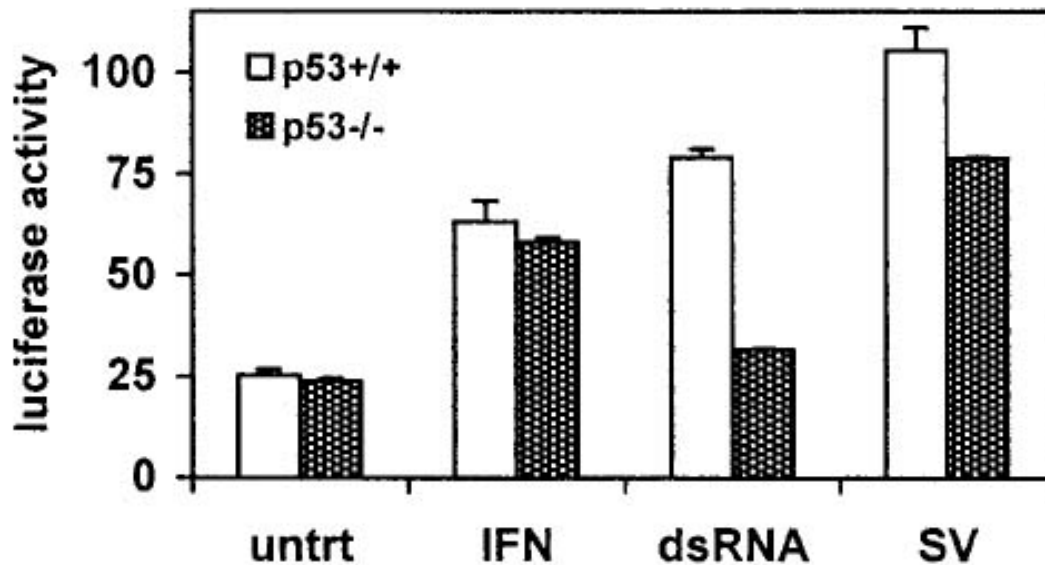
FIG. 4. ISG15 promoter activity mimics endogenous ISG15 mRNA regulation by p53, dsRNA, and virus. Cells (6×10^5 HCT 116) were seeded in 32-mm plates and allowed to attach overnight. Cells were transfected with 500 ng of pGL3/ISG15-Luc, 50 ng of pRL null (Promega), and 450 ng of pcDNA3 for carrier DNA by using Lipofectamine Plus (Life Technologies) following the manufacturer's instructions. Twenty-four hours posttransfection, the medium was aspirated and replaced with medium containing either 1,000 U of IFN-α/ml, 50 μg of dsRNA/ml, or Sendai virus (multiplicity of infection, 10). Cells were incubated for 12 h and then lysed, and luciferase assays were performed. Luciferase activity was assessed on 20 μl of each lysate as directed by the supplier (Dual Luciferase Kit, Promega) using a TD 20/20 luminometer (Turner Designs). Luciferase activity is presented as the ratio of firefly activity to renilla activity to control for differences in transfection efficiency. Each data point is the mean of triplicate samples ± the standard error; the data presented are representative of four independent experiments.
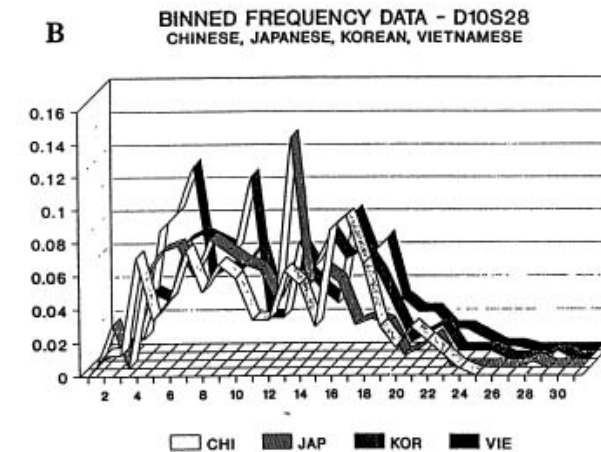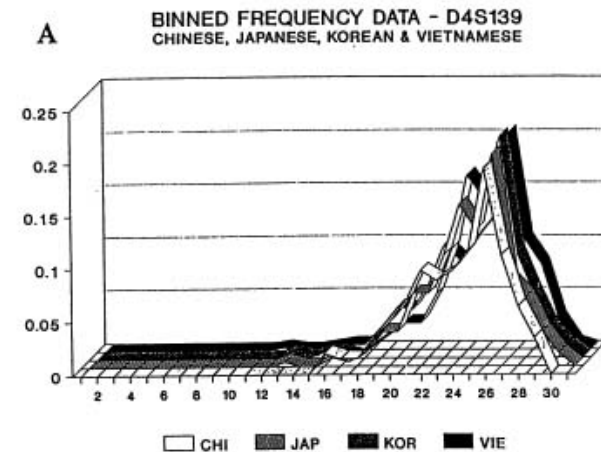
FIG. 4. Fixed bin distribution (histogram) for two loci and four Asian subpopulations (used with permission from John Hartmann): the boundaries of the 30 bins (vertical axis) are determined by the FBI; these bins are not of equal length. Sample sizes (numbers of individuals) for Chinese, Japanese, Korean and Vietnamese are 103, 125, 93 and 215 for D4S139 and 120, 137, 100 and 193 for D10S28. The horizontal axis is the bin number; bins are not of equal length.

Some available plot types **Used and abused**
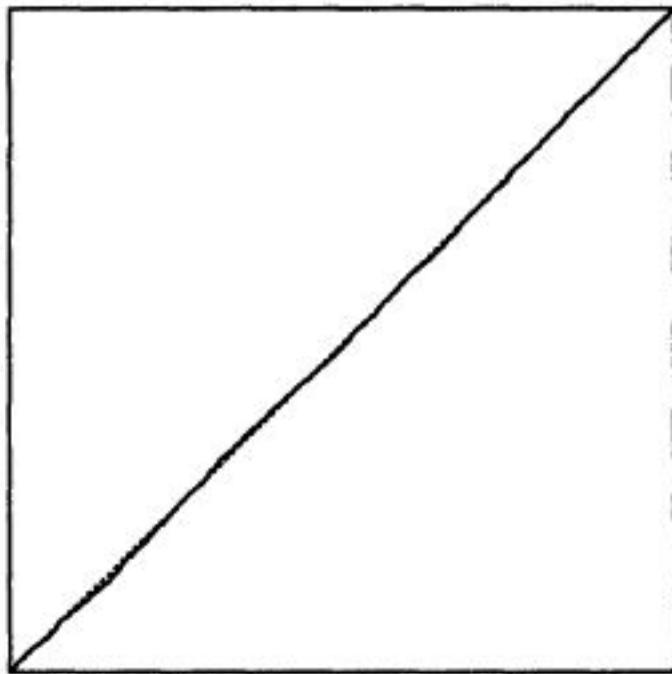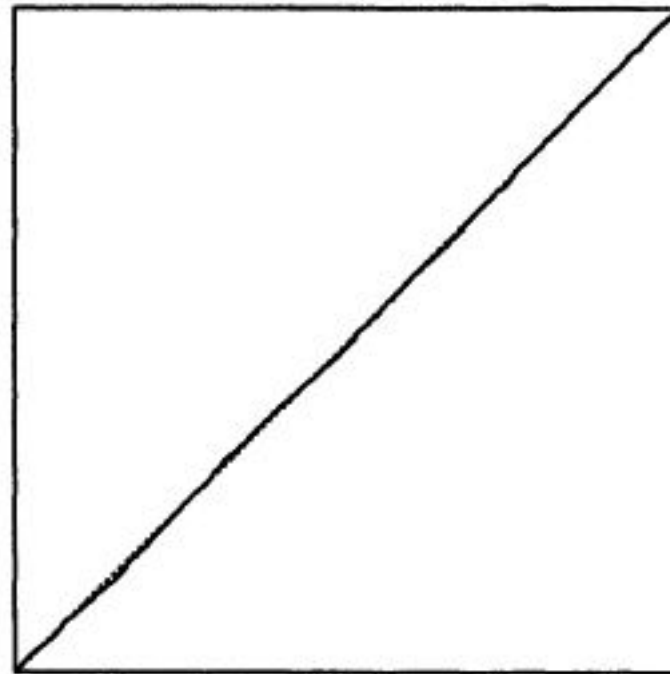
Figure 1. SRQ Plots of T_i/T_n (Vertical Axes) Against i/n (Horizontal Axes) for the Gibbs Sampler (a) and an Alternating Gibbs/Independence Sampler (b) for the Pump Failure Data Based on Runs of Length 5,000. Lines through the origin with unit slope are shown dashed; axis ranges are from 0 to 1 for all axes.

EQUENCY DATA – D4S139
NESE, KOREAN & VIETNAMESE

14 16 18 20 22 24 26 28 30

JAP   KOR   VIE

EQUENCY DATA – D10S28
PANESE, KOREAN, VIETNAMESE

14 16 18 20 22 24 26 28 30
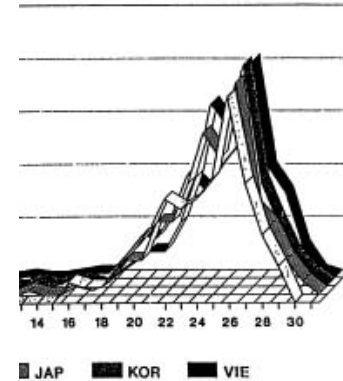
JAP   KOR   VIE
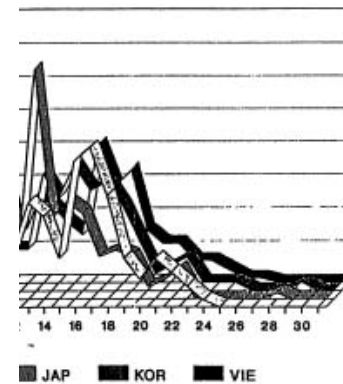
tion (histogram) for two loci and four d with permission from John Hart- e 30 bins (vertical axis) are determined t of equal length. Sample sizes (num- ese, Japanese, Korean and Vietnamese r D4S139 and 120, 137, 100 and 193 for D10S28. The horizontal axis is the bin number; bins are not of equal length.

Some available plot types

Some available plot types

http://flowingdata.com/category/visualization/ugly-visualization/
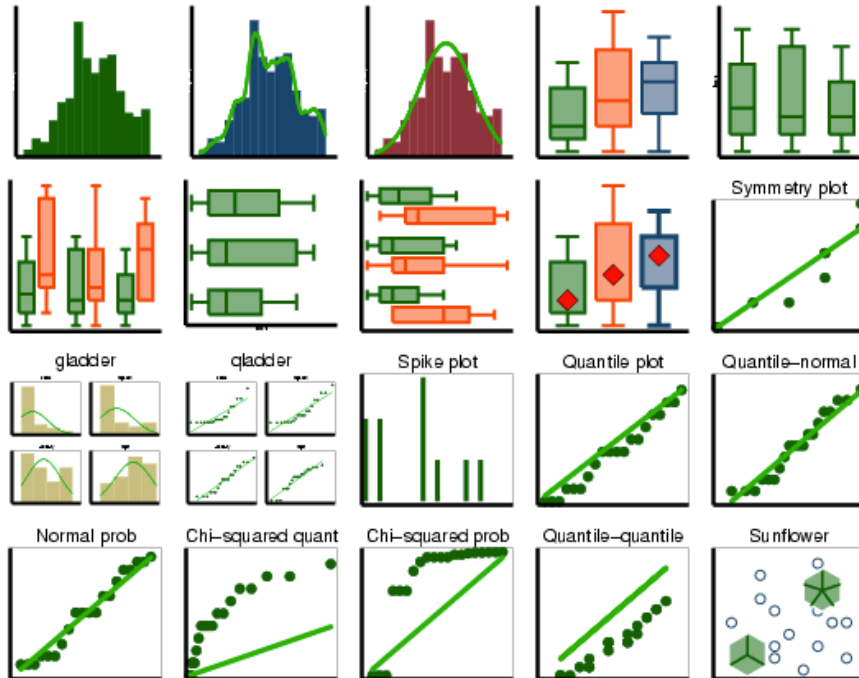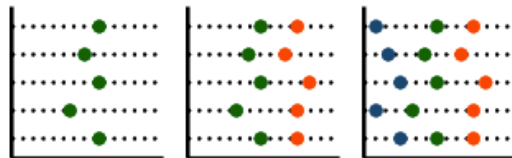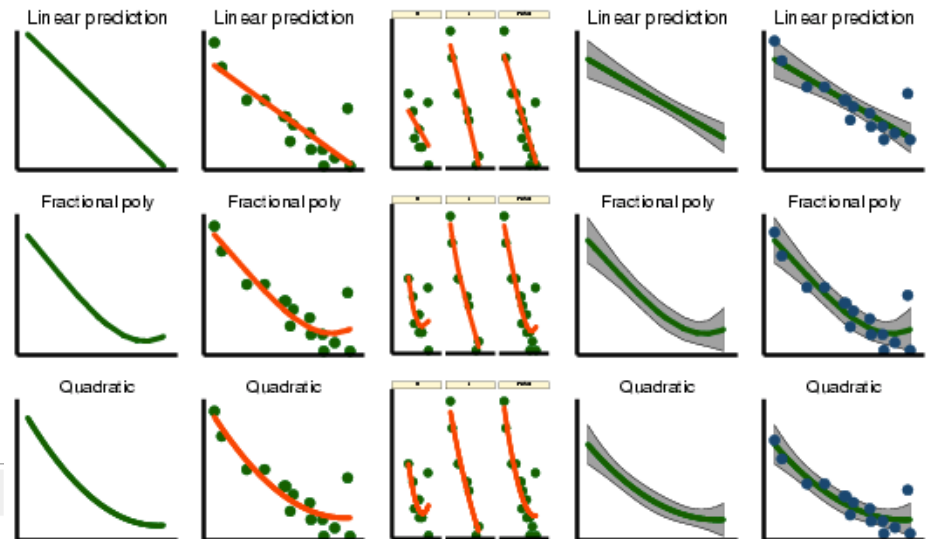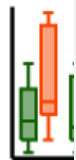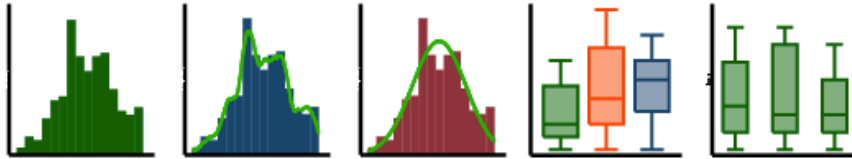
So you want to make a graph…?

- Example from our work: One year of temperature data in the Hospital Microbiome Project

- Collected 5-minute intervals

- We can averaged over:
  – Hourly intervals
  – Daily intervals
  – Weekly intervals

- Examples in Stata:
  – Line, scatter, caps, area, dot plots, scatterplot matrices, heat map

5-minute air temperatures
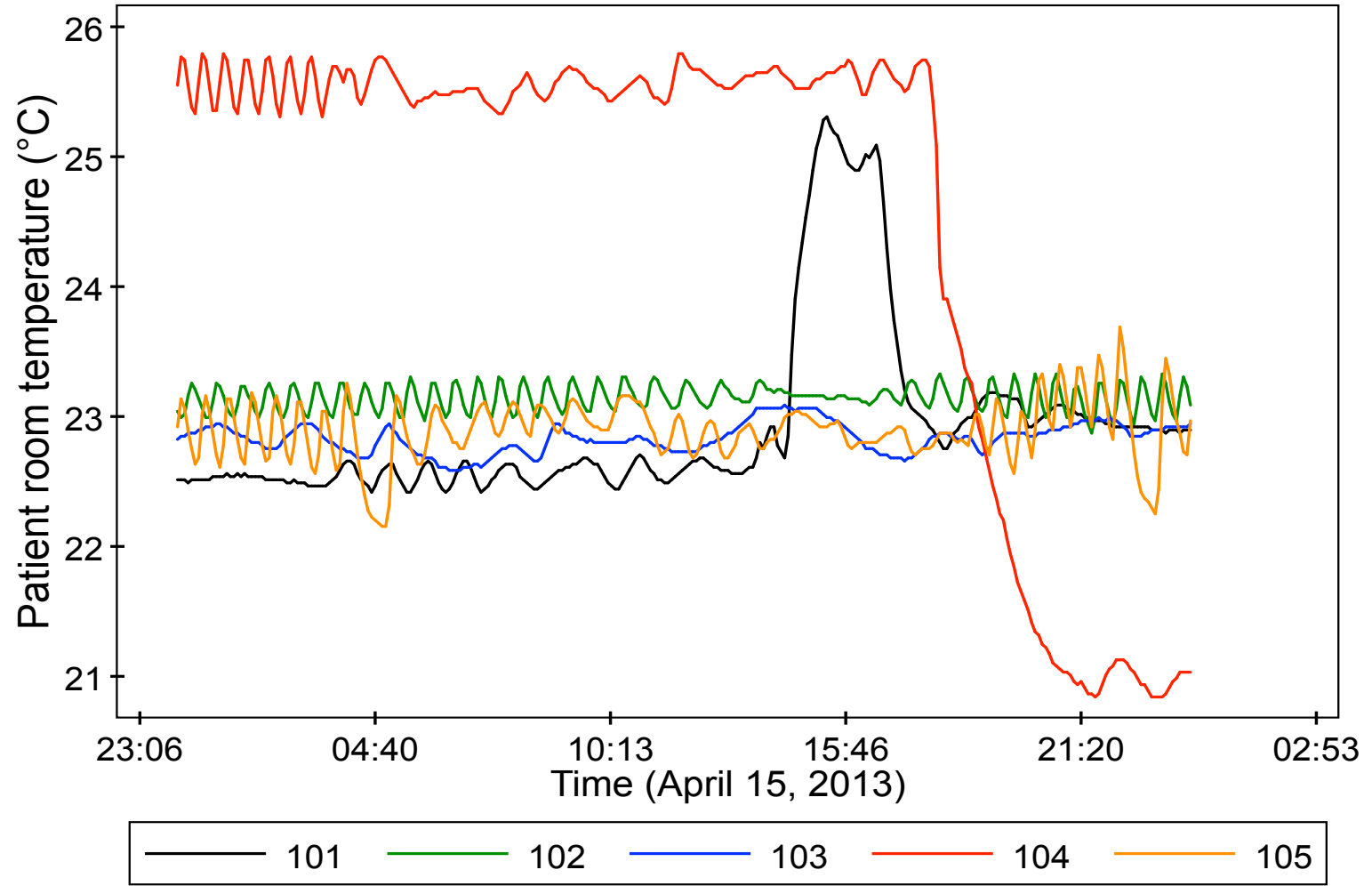
Daily average air temperatures
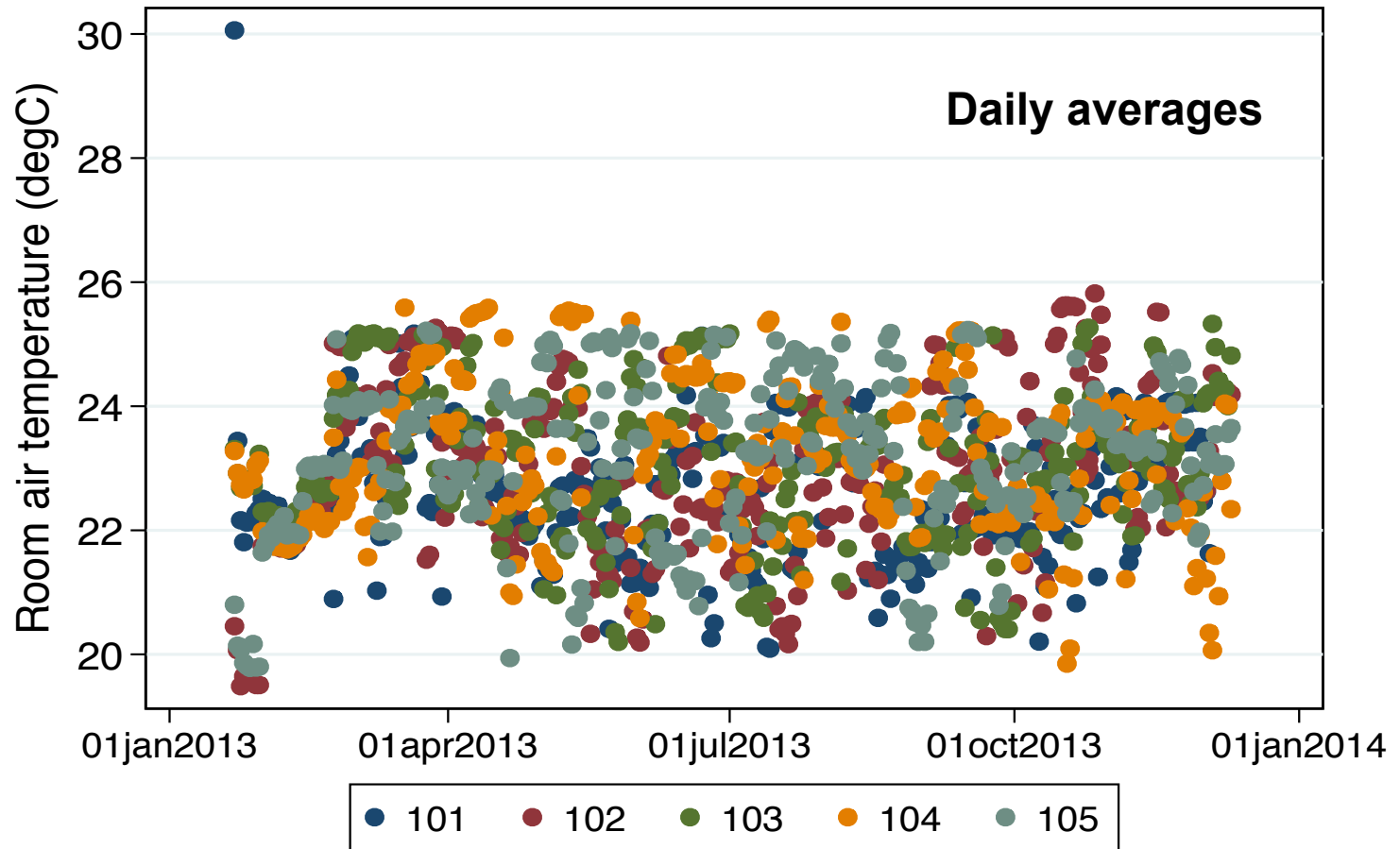
Hourly mean air temperatures: Distributions

Similar distributions across patient rooms and nurse stations | Range 19-27°C 66-80°F

IQR = 22.6-24.7°C (72-76°F)
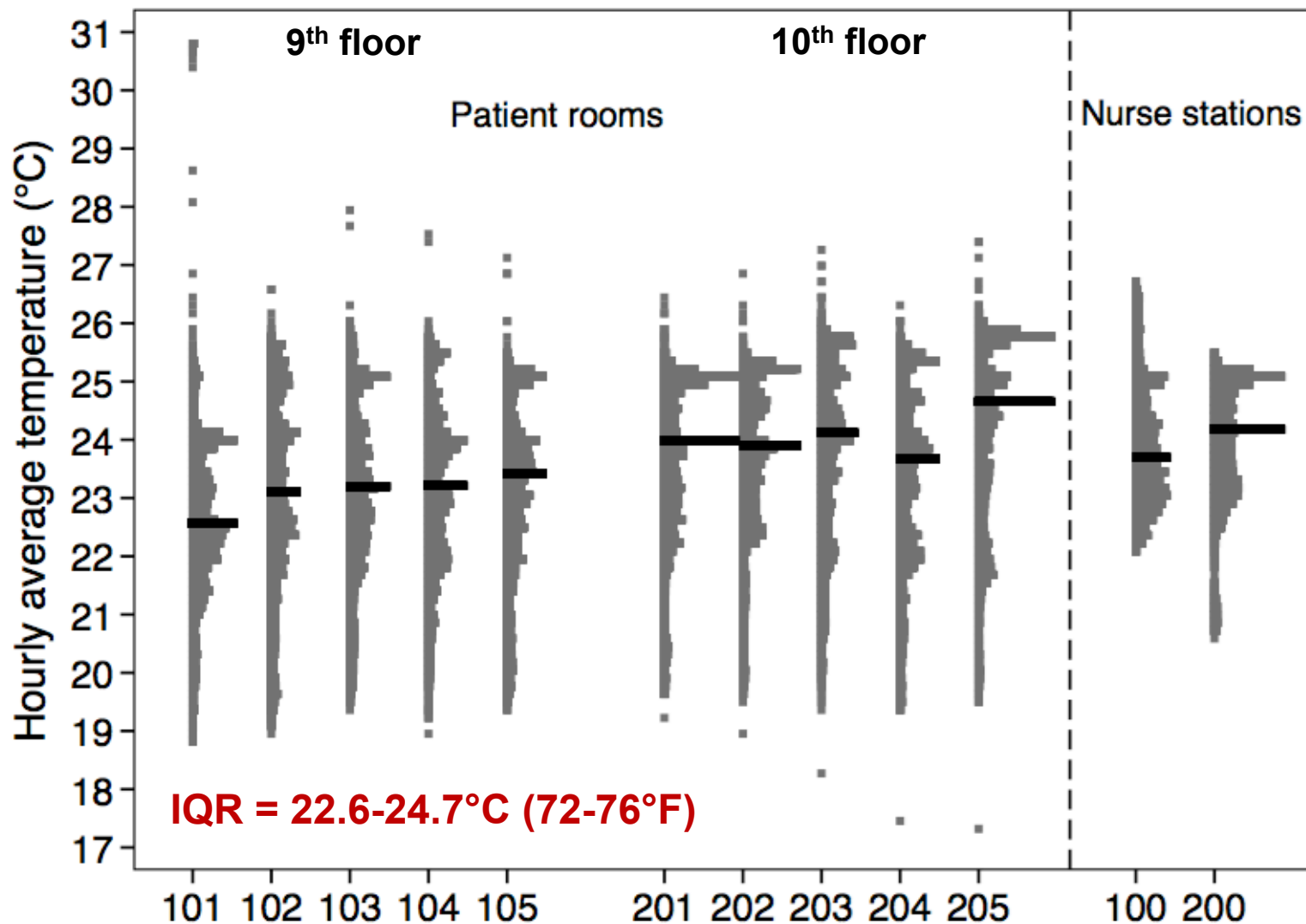
Daily mean air temperatures: Scatterplot matrices

Almost no correlation between rooms
- *Most comparisons: R < 0.2*
- *Differences of >2°C fairly common*
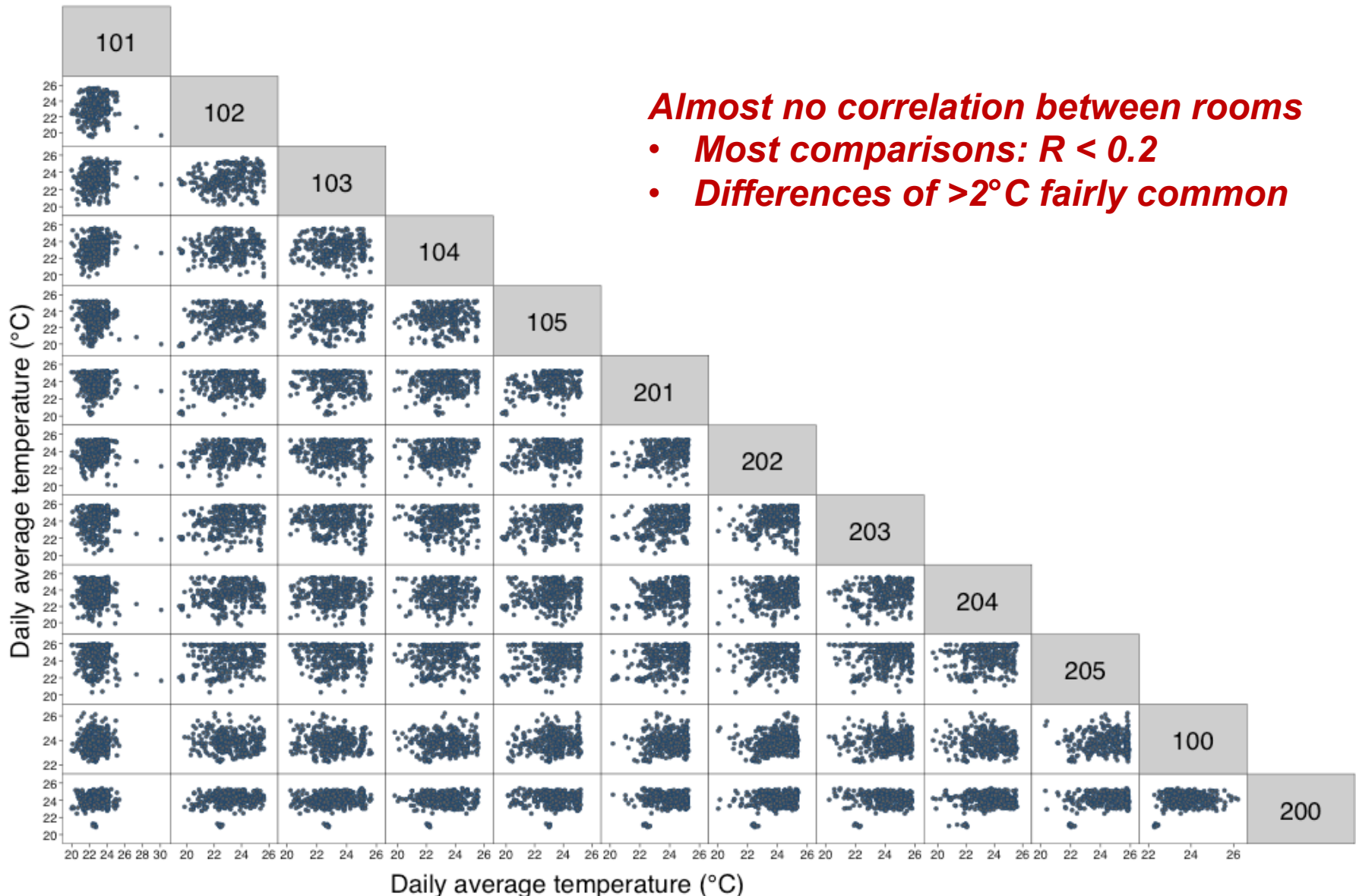
Weekly mean temperatures: Heat map
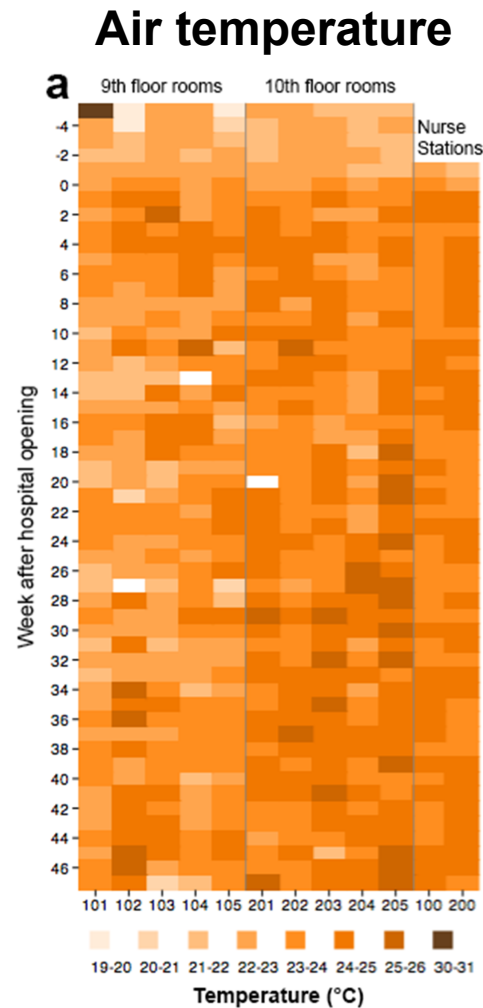
Air temperature

19 to 26 °C

Between-room *R* <0.2

Ramos et al. **2015** *PLOS ONE* 10(3):e0118207

Hospital *Microbiome*

Median Air temperatures ~1°C higher on 10th floor
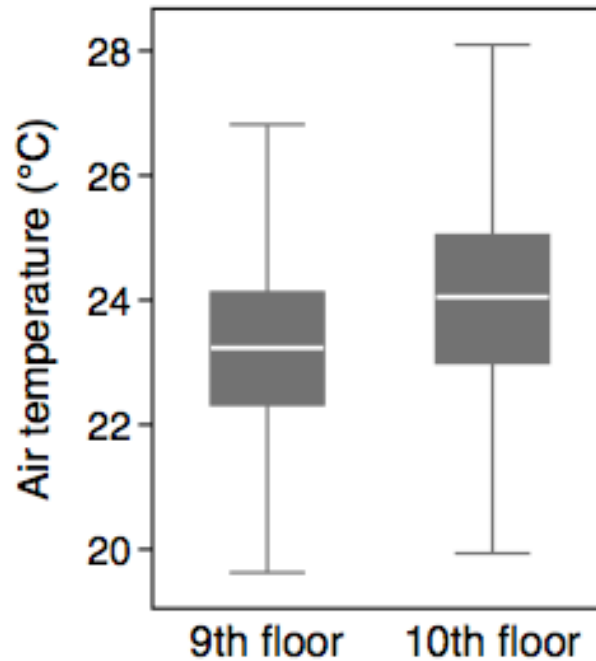
Data visualization resources
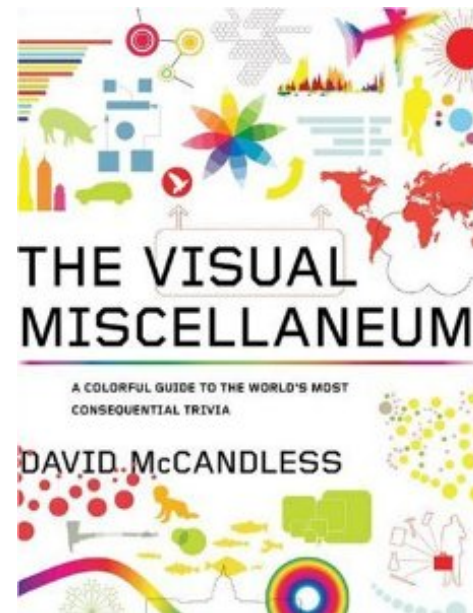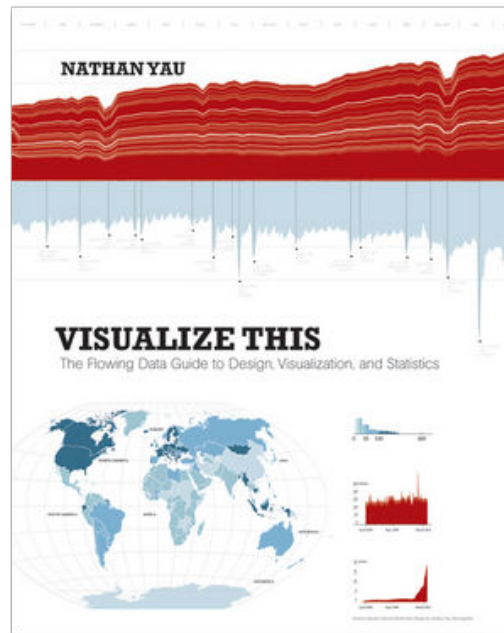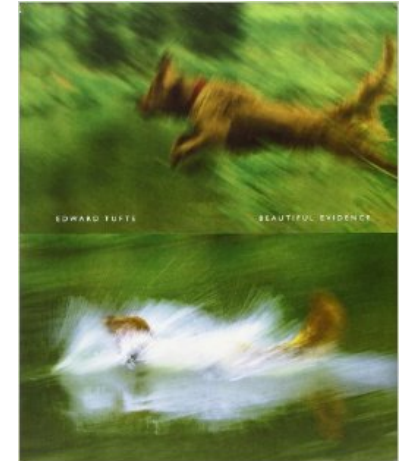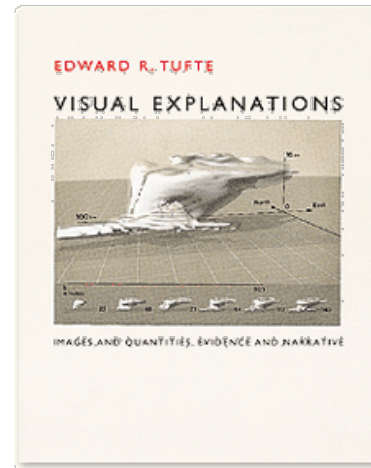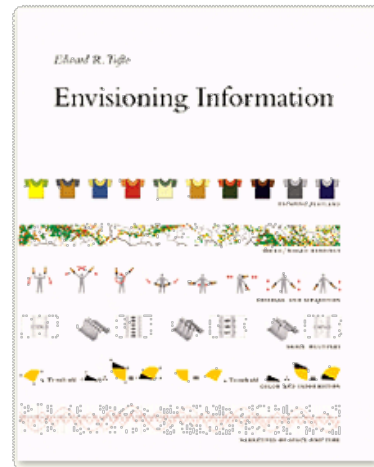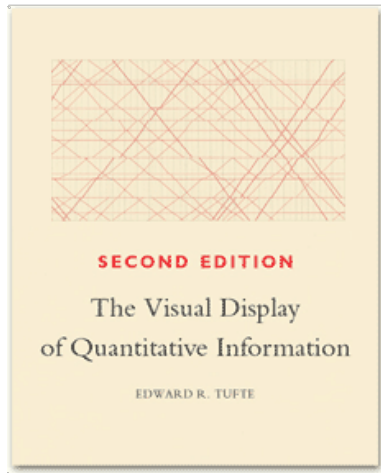
Data visualization tools
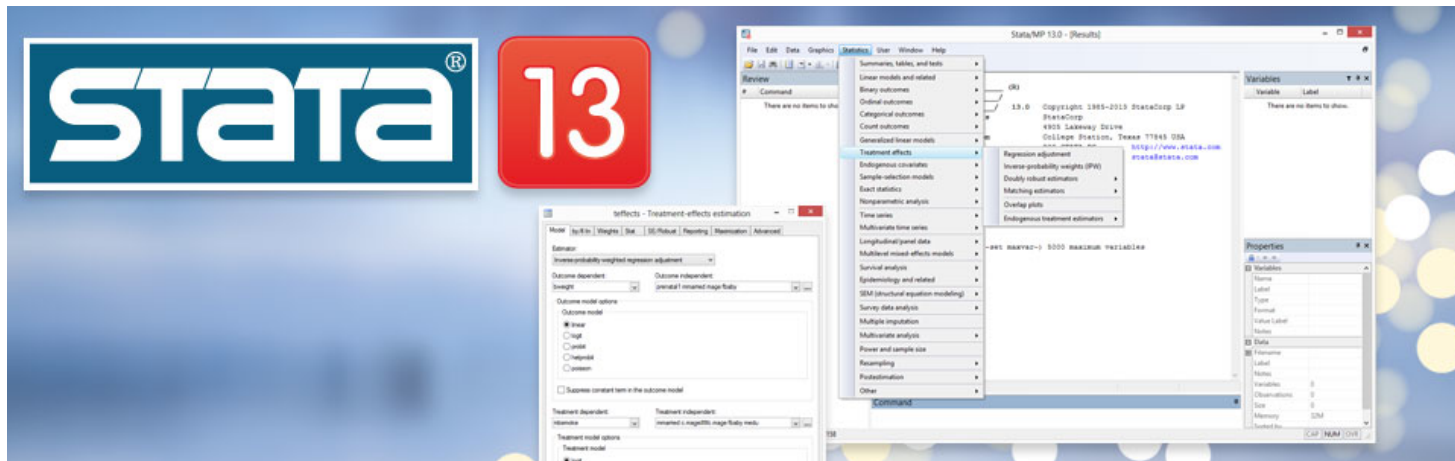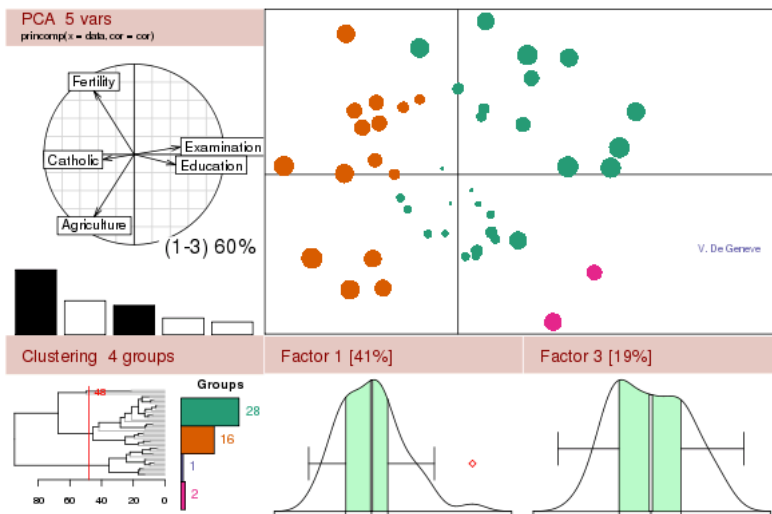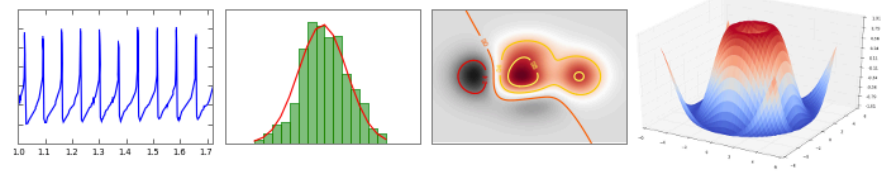
Others: Excel, SPSS, Matlab, and many more

Data visualization exercise

- Tall buildings data – how best to plot it?